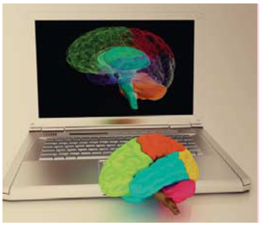
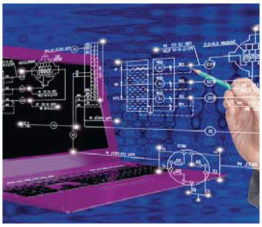
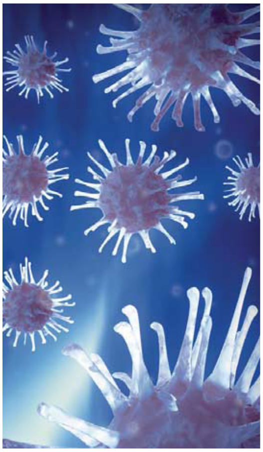




Advances in Transdisciplinary Engineering series

volume 12

Transdisciplinary Engineering for Complex Socio-technical Systems – Real-life Applications


Proceedings of the 27th ISTE International Conference on Transdisciplinary Engineering, July 1 – July 10, 2020


EDITED BY
Jerzy Pokojski
Maciej Gil
Linda Newnes
Josip Stjepandić
Nel Wognum

Transdisciplinary Engineering for Complex Socio-technical Systems – Real-life Applications

Transdisciplinary engineering transcends other inter- and multi-disciplinary ways of working, such as Concurrent Engineering (CE). In particular, transdisciplinary processes are aimed at solving complex, ill-defined problems, or problems for which the solution is not immediately obvious. No one discipline or single person can provide sufficient knowledge to solve such problems, so collaboration is essential.

This book presents the proceedings of the 27th ISTE International Conference on Transdisciplinary Engineering, organized by Warsaw University of Technology, Poland, from 1-10 July 2020. ISTE2020 was the first of this conference series to be held virtually, due to the COVID-19 restrictions. Entitled *Transdisciplinary Engineering for Complex Socio-technical Systems - Real-life Applications*, the book includes 71 peer-reviewed papers presented at the conference by authors from 17 countries. These range from theoretical and conceptual to strongly pragmatic and addressing industrial best practice and, together with invited talks, they have been collated into 9 sections: Transdisciplinary Engineering (7 papers); Transdisciplinary Engineering Education (4 papers); Industry 4.0, Methods and Tools (7 papers); Human-centered Design (8 papers); Methods and Tools for Design and Production (14 papers); Product and Process Development (9 papers); Knowledge and Data Modeling (13 papers); Business Process and Supply Chain Management (7 papers); and Sustainability (2 papers).

The book provides an overview of new approaches, methods, tools and their applications, as well as current research and development, and will be of interest to researchers, design practitioners, and educators working in the field.

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Preface

This book of proceedings contains papers that have been peer-reviewed and accepted for the 27th ISTE International Conference on Transdisciplinary Engineering, organized by Warsaw University of Technology, Poland, July 1 – 10, 2020. TE2020 has been the first conference in the series that was organized in a virtual manner due to the COVID-19 world-wide crisis. The papers published in this book of proceedings, as well as video presentations, were accessible during July 2020 in Webex Teams, while questions and answers were being exchanged.

This is the eleventh issue of the series "Advances in Transdisciplinary Engineering", which publishes the proceedings of the TE (formerly: CE) conference series and accompanying events. The TE conference series is organized annually by the International Society of Transdisciplinary Engineering, in short ISTE (www.intsoctransde.org), formerly called International Society of Productivity Enhancement (ISPE, Inc.) and constitutes an important forum for international scientific exchange on transdisciplinary engineering. These international conferences attract a significant number of researchers, industry experts and students, as well as government representatives, who are interested in recent advances in transdisciplinary engineering research, advancements and applications.

The concept of Transdisciplinary Engineering includes Concurrent Engineering (CE), but also transcends it. The concept of CE, developed in the 80's, implies that different phases of a product life cycle are conducted concurrently and initiated as early as possible within the Product Creation Process (PCP), including the implications of this approach within the extended enterprise and networks. The main goal of CE is to increase the efficiency and effectiveness of the PCP and to reduce errors in the later phases, as well as to incorporate considerations for the full lifecycle, through-life operations, and environmental issues. In the past decades, CE has become the substantive basic methodology in many industries (e.g., automotive, aerospace, machinery, shipbuilding, consumer goods, process industry, environmental engineering) and is also adopted in the development of new services and service support. Collaboration between different disciplines is key to successful CE.

While for several decades CE proved its value in many industries and still continues to do so, many current engineering problems require a more encompassing approach. Many engineering problems have a large impact on society. For example, the development of self-driving cars requires taking into account changes in regulations for managing responsibilities, adaptation of road networks, political decisions, infrastructures for energy supply, etc. The impacted society may also be the business environment of networks of companies and supply chains. For example, the adoption and implementation of Industry 4.0 requires taking into account the changes to be expected in the business environment, the people, their jobs, the knowledge needed, technology, organizational rules and behaviours. These kind of engineering problems also require collaboration, but not only between technical disciplines. Disciplines from other scientific fields need to be incorporated in the engineering process, like disciplines from social sciences (governance, psychology, etc.), law, medicine, or other fields, relevant for the problem at hand.

The concept of transdisciplinary engineering transcends inter- and multi-disciplinary ways of working, like in CE. In particular, transdisciplinary processes are aimed at solving complex ill-defined problems or problems for which the solution is not obvious from the beginning. While such problems, including their solutions, have a large impact on society and the context in which the problems exist, it is important that people from society and practice collaborate with people from different relevant scientific communities. Neither one discipline nor one person can bring sufficient knowledge for solving such problems. Collaboration again is essential but has become even more demanding. Disciplines should be open to other disciplines to be able to share and exchange the knowledge necessary for solving the problem.

Any engineering problem can be put is a context in which the problem is to be solved or in which the solution for the problem is expected to be used. For researchers and engineers, it is important to take into account this context. This could be done, for example, by collaborating with researchers who can study user acceptance of the envisioned solution or with researchers who can apply suitable methods to acquire user preferences in the respective context and translate them into the necessary requirements for the solution to be developed. Validation of a proposed engineering solution will benefit also by incorporating people from other scientific fields

The conference is entitled: “Transdisciplinary Engineering for Complex Socio-technical Systems in perspective of Real-life Application”. The TE2020 Organizing Committee has identified 36 thematic areas grouped into nine themes within TE and launched a Call for Papers accordingly. More than 80 papers have been submitted from all continents of the world. The submissions as well as invited talks have been collated into nine themes.

The Proceedings contains 71 peer-reviewed papers presented at the conference by authors from 17 countries. These papers range from the theoretical, conceptual to strongly pragmatic addressing industrial best practice. The involvement of industry in many of the presented papers gives additional importance to this conference.

This book on “Transdisciplinary Engineering for Complex Socio-technical Systems in perspective of Real-life Application” is directed at three constituencies: researchers, design practitioners, and educators. Researchers will benefit from the latest research results and knowledge of product creation processes and related methodologies. Engineering professionals and practitioners will learn from the current state of the art in transdisciplinary engineering practice, new approaches, methods, tools and their applications. The educators in the TE community gather the latest advances and methodologies for dissemination in engineering curricula, to prepare students for transdisciplinary collaboration in complex engineering processes, while the community also encourages educators to bring new ideas into the field. With the annual contributions of many researchers and practitioners the book series will contribute to the further development of the concept of Transdisciplinary Engineering.

The proceedings are subdivided into several parts, reflecting the themes addressed in the conference programme:

Part 1 is entitled Transdisciplinary Engineering and contains seven papers that address the concept of TE. Some papers contain research into understanding the concept of TE, while others present work in which a transdisciplinary approach is or has been applied in developing a complex system.

Part 2 contains papers in the area of Transdisciplinary Engineering Education, an important field in our conferences. Empowering students with the knowledge to collaborate in complex project like TE projects is very important. Four papers present different ways in which students learn to deal with different types of knowledge

Part 3, Industry 4.0, Methods and Tools, contains seven papers with subjects like bibliometric analysis for smart farming, information traceability to detect non-conformities in production, design languages for automatic generation of digital twins of CBSs, Enterprise Maturity Levels measurement, the use of IoT in industrial logistics, a design support tool for the development of CPSs, and reference architectures for Industry 4.0.

Part 4 contains eight papers in the theme Human-Centred Design addressing e.g., a transdisciplinary assessment matrix for human-machine interaction, innovative tools for designing ergonomic control dashboards, ergonomics in a university hospital, informal requirements analysis for a prosthetic device, radiographic bone age assessment, technology for the manufacturing of innovative orthopaedic corsets, evaluation of humanoid robot design base on global eye-tracking metrics, and transdisciplinary design of an air mobile stroke unit.

Part 5 is entitled Methods and Tools for Design and Production. It contains 14 papers focusing on engineering and logistic subjects like Berth allocation and quay crane assignment, control and coordination, tools for sheet metal forming, mass customization services through VR-enabled chatbot systems, green flatcar transportation scheduling in shipbuilding, FMEA with a multi-criteria approach, MCDM application in early stages of the PDP, context-sensitive evaluation of PSS solutions, change propagation in product realization, impact assessment of food safety news, automated generation of a digital twin of a manufacturing system, phenomena in safety systems made of hyper-elastic materials, verification of a method for building a very flexible wing generative model, and a thermomechanical model of a crank mechanism.

Part 6 contains nine contributions on Product and Process Development with various contributions like a design methodology for smart PSS development, digital collaboration techniques for interdisciplinary collaboration, energetic autonomy of UAV, a requirements management tool for specification and analysis of product lines, a multi-disciplinary optimisation framework for dual-mode launch vehicle concepts, factory planning by automated generation of a digital twin, design of injection moulding for LED lamp power supply, morphic arrangement of high flexibility and aspect ratio wing, and hierarchical models for vulnerability analysis of road networks.

Part 7 is entitled Knowledge and Data Modelling. It contains 13 papers with a focus on modelling, like a synthetic dataset for deep learning noise filtering, BIM maturity models, issues in semantic interoperability in integrated manufacturing, neural network for forecasting intermittent demand, semantic ontology for identification of trademark case precedents, integrated information for customized product development, reliability prediction for aircraft component behaviour by using textual elements, parametric modelling of steel connectors, knowledge-based assisting tools, agile engineering change management approach, cost modelling of recycling carbon fibre composites, modularity and configuration for IoT, and robust CAD modelling for industrial application.

Part 8 deals with Business Process and Supply Chain Management. This part contains seven contributions on identifying superfluous work in shop floor management digitalisation, conceptual model for process capability, practice-based learning for successful application of supply chain 4.0 technology, foreign direct investment and enterprise ownership, bibliometric analysis of production planning optimization, delivery demand peak levelling based on capability assessment of customer's acceptance, and an adaption of the internal quality auditing process.

Part 9 contains contributions on Sustainability addressing global transport challenges in reducing emission, and a CAD material skeleton approach for sustainable design.

We acknowledge the high-quality contributions of all authors to this book and the work of the members of the Scientific Committee who assisted with the blind peer-review of the original papers submitted and presented at the conference. Readers are sincerely invited to consider all of the contributions made by this year's participants through the presentation of TE2020 papers collated into this book of proceedings. We hope that they will be further inspired in their work for disseminating their ideas on transdisciplinary engineering within the ISTE community.

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Transdisciplinary System of Systems Development in the Trend to X4.0

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Abstract. Since the announcement of Industry 4.0 in 2012, multiple variants of this industry paradigm have emerged and built on the common platform of Internet of Things. Traditional engineering driven industries such as aerospace and automotive are able to align with Industry 4.0 and operate on requirements of the Internet of Things platform. Process driven industries such as water treatment and food processing are more influenced by societal perspectives and evolve into Water 4.0 or Dairy 4.0. In essence, the main outcomes of these X4.0 (where X can be any one of Quality, Water or a combination of) paradigms are facilitating communications between socio-technical systems and accumulating large amount of data. As the X4.0 paradigms are researched, defined, developed and applied, many real examples in industries have demonstrated the lack of system of systems design consideration, e.g. the issue of training together with the use of digital twin to simulate operation scenarios and faults in maintenance may lag behind events triggered in the hostile real world environment. This paper examines, from a high level system of systems perspective, how transdisciplinary engineering can incorporate data quality on the often neglected system elements of people and process while adapting applications to operate within the X4.0 paradigms.

Keywords. Industry 4.0; Water 4.0; Quality 4.0; System architecture; System of systems; Socio-technical systems

Introduction

The Industry 4.0 initiative has received increasing attention in recent years. The initiative defines future production environment specifications and allows customer and individual expectations to influence all phases of the product development lifecycle, such that last-minute changes are incorporated in the final product [1].

Advancement of the Internet, e-commerce, and social networks empowers consumers with more product details, including new product launches and in-depth product reviews. The global manufacturing supply chain is undergoing transformation to produce highly customised products tailored to individual needs by digitising and revolutionising daily business processes and administrative tasks with an associated initiative put forward by Bienhaus & Haddud [2] as Procurement 4.0. Traditional engineering driven industries such as aerospace and automotive have incorporated Industry 4.0 with significant technological advancement and are heavily digitised to suit the operating requirements of the Internet of Things (IoT). Nevertheless, Castelo-Branco et al [3] concluded from their study that only 5 countries in EU were

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comprehensively prepared for Industry 4.0 due to the need for a well-developed digital infrastructure coupled with strong big data analytical capabilities.

In this scenario, other industry sectors are forced to adopt similar approaches to satisfy increasingly sophisticated consumers by developing individualised business models. Beckett et al [4] explored emergent digital age quality management concepts under the headings of "Quality 4.0" and "Water 4.0" as a drive to improve the dairy industry. In this context, traditional engineering disciplines such as chemical and process engineering are combined with computer science, information systems and systems engineering disciplines, increased use of smart sensors in water and food quality monitoring was the key to this implementation. From this observation, it is convenient to note the phenomenon as "X4.0" where X can be any industry or process that becomes a term related to a paradigm shift on the common platform of IoT.

As the X4.0 paradigms are researched, defined, developed and applied, many real examples in industries have demonstrated the lack of system of systems design consideration, especially due to the nature of socio-technical processes and human participation. For example, process driven industries such as water treatment and food processing are influenced more by societal perspectives. Although earmarked to pursue Quality 4.0 and Water 4.0, training on IoT platform in water, food safety and environments, particularly with the use of digital twin to simulate operation scenarios and faults in maintenance still lags behind events triggered in the hostile real-world environment [5]. In the oil and gas industry, Lu et al [6] analyzed typical application scenarios upstream, midstream and downstream of the fuel supply chain. They concluded that "Oil and Gas 4.0" would succeed if industry personnel were trained to apply a highly digitised data-driven intelligence system to practical engineering.

This paper examines, from a high-level system of systems perspective, how transdisciplinary engineering can incorporate data quality on the often neglected system elements of people and process while adapting applications to operate within the X4.0 paradigms.

1. The Challenges of X4.0

With the advancement in IoT, global business networks rely more and more on the information technology and communication infrastructure to do business. The change in business processes triggers typical issues in X4.0 operations that include shorter product life cycle, more supply variability, difficult collaboration, risk to confidentiality, conflicts in intellectual property, opportunity loss, capacity constraints and others [7]. Simply drawing upon the advantage of increased amount and speed of data availability (or the big data) on the IoT platform is not enough to foster efficient and effective decision-making in the system of systems. A strategic framework is required to integrate the upstream and downstream managers that creates and adds value to the products or services that ends up in the hands of the consumers [8]. X4.0 systems have inherent challenges as IoT technologies become the main platform to do business. In this section, the issues of changing the business mode from traditional means to an Internet based system of systems are explored.

1.1. System complexity challenges

Unlike a normal enterprise, a X4.0 environment is formed from a number of autonomous enterprises. According to O'Donovan et al [9], Industry 4.0 paradigm combined many legacy systems through industrial cyber-physical connectivity. However, incompatibility of technologies and architectures are still not fully resolved. Complexity existed in the "fog and cloud" interfaces resulting in latency and reliability issues, and the environment might not be optimised for ultimate performance.

Aziz et al [10] studied the implications of Industry 4.0 in New Zealand dairy industry – the leading industry in the country. They found that apart from quality control of dairy products, many other disciplines were inter-connected, including livestock management (number and health), transport, land use. Data transparency in terms of data flow and contextual integrity among operating units was important to ensure that corresponding business processes among trading partners could be developed and synchronised at a high level of visibility.

The global environment is dynamic and often affected by customer preferences such as seasonal requirements. Many customers expect a build-to-order strategy to be adopted among the participating enterprises. As cloud based system becomes the basis of communication among manufacturing enterprises, their interoperability will play a role of vital importance [11]. Risk-influencing determinants such as forecast uncertainty, demand variability, contribution margin, and time of delivery contributed to the responsiveness of the X4.0 system. Hence, modelling as a means of controlling the system's performance by design would be an important measure to manage the inherent complexity of the system of systems in X4.0 environment.

1.2. Societal challenges

Company operations in a X4.0 environment are effectively a system that consists of numerous organisations with different business perspectives (such as suppliers, manufacturers, distributors and customers). Although the usage of IoT is a common issue, social pressure emerged within and among organisations when the companies involved migrate to X4.0 paradigm. Turban et al [12] proposed a framework using Collaboration 2.0, which is a kind of social software. They investigated how it could improve with group decision making process. A "fit-viability" model was developed to assess the environment in which the social software tools could be useful.

Managers in the global business network should understand the institutional pressure applied and recognise they are all embedded in a broader ecosystem, when interacting with their X4.0 counterparts. For example, the United Nations [13] has declared the 2030 sustainability development requirements. Water accessibility and quality is one of the 17 goals that involve almost all disciplines and governments. Different types of institutional isomorphism, namely coercion, mimesis, and norms, could drive different levels of inhibition on the X4.0 system performance such as losing business opportunities. Likewise, Annosi et al [14] were interested in the attitude of owners and managers in Agriculture 4.0. The agricultural sector is primarily small and medium enterprises and the adoption of IoT is still limited. Perception of the utility of 4.0 technologies directly affected investment decisions.

For each business process there would be a number of headline systems that are relied upon. These interrelationships should be mapped out in a process known as situational awareness. By accurately mapping business processes to information systems, system operational risk could be identified leading to real business risk and subsequently vulnerability could be determined from the use of graphical representation of the tools [15].

Therefore, a crucial task in building a X4.0 system is to clearly define the *social context* with which the X4.0 style business is going to operate. In this circumstance, a transdisciplinary system design would be able to determine the physical and structural properties of collaboration, the culture, business practices, security processes and governance issues [16].

1.3. Technological challenges

An IoT-enabled global business network requires product information to be transferable in electronic format. A crucial condition to enable this capability is the compatibility of product lifecycle information models for decision making based on data gathered through different parts of the product development, manufacturing, sales and services processes [17]. Fundamental research is required into information systems models, smart embedded systems, short and long distance wireless communication technologies, data management and modelling, design for X, adaptive production, statistical predictive maintenance and management of product end of life [18].

To complement the need for prototyping and physical testing, a virtual copy of the system (sometimes described as "digital twin"), that can interact with the physical counterparts in a bi-directional way, seems to be a promising enabler to replicate some X4.0 functions in real time for analysis and decision-making [19]. However, the control of the physical system by the "digital twin" has not been fully established.

Pacchini et al [20] attempted to develop an assessment model that could determine the readiness of a company in the implementation of Industry 4.0. Eight technology enablers were selected by reference to existing literatures. Similarly, Miranda et al [21] applied the 3S concept, i.e. sensing, smart and sustainable, to Agri-Food 4.0. They were concerned about lack of design roadmaps that could enable development of 3S-based products for applications in agri-food production. The quality of data returned from these products has serious risks of affecting decisions in the business.

Inter-mixing of different legacy systems and continuous adoption of new technologies and techniques seem to be the norm for X4.0 systems. An open, agile system architecture for developing the operation platform is required.

2. Requirements for a X4.0 System

The need for a X4.0 system to overcome complexity, societal and technological challenges calls for a new system architecture that can be more broadly encompassing and versatile. Past system architectural constructs have proved to be too rigid for modern business practices [22]. Even back in 1989, the US Department of Defence [23] queried the need to send human pilots going into mission environment if a remotely piloted machine could be designed.

2.1. Knowledge sharing and decision making in X4.0 Systems

From system's perspective, an X4.0 system demands involvement of multiple systems with a variety of disciplines including engineering, computer science, information system and specialist user disciplines. Through IoT connection, people with different background knowledge and potentially different cultural norms, together with other stakeholders such as financial institutions, governments and certification authorities, will have strong influence on the development.

The dispersed environment nature of X4.0 essentially evolves into different types of business environments. In a known, ordered environment, repeatability allows for predictive models to be established and best practice identified. This is seen as the domain of process re-engineering pursuing efficiency, where the appropriate actions are categorize and respond. An example is the normal clinical treatment in medical system. In an unknown, ordered environment where cause and effect are not immediately evident (or may be known by only a few people), appropriate actions are analyse and respond. This is seen as the domain of systems thinking of the learning organization and the adaptive enterprise, where experimentation, expert opinion, fact-finding, and scenario planning are combined. An example is the emergency hospital episodes [24].

In an unordered environment where complex relationships and interactions cause unexpected outcomes, appropriate actions are detect, categorise and respond. In this environment there may be a string of cause and effect relationships between the agents. Both the number of agents and the number of relationships make categorization or analysis difficult. Emergent patterns may be perceived but not predicted. An example is the joint military-civilian emergency response exercise where many issues had to be tracked in parallel [25].

In an unordered environment that seems chaotic, an appropriate response is to act, detect and respond. An example is an earthquake accident scenario where the immediate response is to act to minimise casualties and prevent further damages. In this situation, multiple decision-makers observe the same phenomenon from different points of view. Those most comfortable with stable order will try to create or enforce rules. Experts seek to conduct research and accumulate data. Politicians seek to increase the number and range of their contacts. Interestingly, dictators are eager to take advantage of this chaotic situation and seek absolute control. Collaborating to reach consensus on a series of small actions can change this situation [26].

Hence, a X4.0 paradigm is centred around the decision system at the core, and supported by a knowledge network with collaborating knowledge agents. The knowledge network supports the performance of tasks. It supports and is supported by the collection and distribution of information, and is populated by collaborating knowledge agents who may be individuals, teams or organizational groups.

2.2. Modelling a X4.0 System

Beckett and Daberkow [27] found that in the evolution of Industry 4.0 environment, some people might be displaced from their traditional occupations by intelligent agents and smart machines. At the same time there might be a shortage of people skilled in the development of these technologies. Hence, societal changes could see more people undertaking a succession of short-term project assignments. They represented Industry 4.0 and the related Work 4.0 paradigms in an integrated system as shown in Figure 1.

It is apparent from Figure 2 that X4.0 depends on data. The quality of data becomes an important consideration to prevent “garbage-in-garbage-out” problem. Managing data integrity is a system by its own right. This observation reflects close interactions between cyber-physical system and data analytic through numerous sensors and interfaces of analyses. Subsystem evolution is informed by ongoing technology and business research.

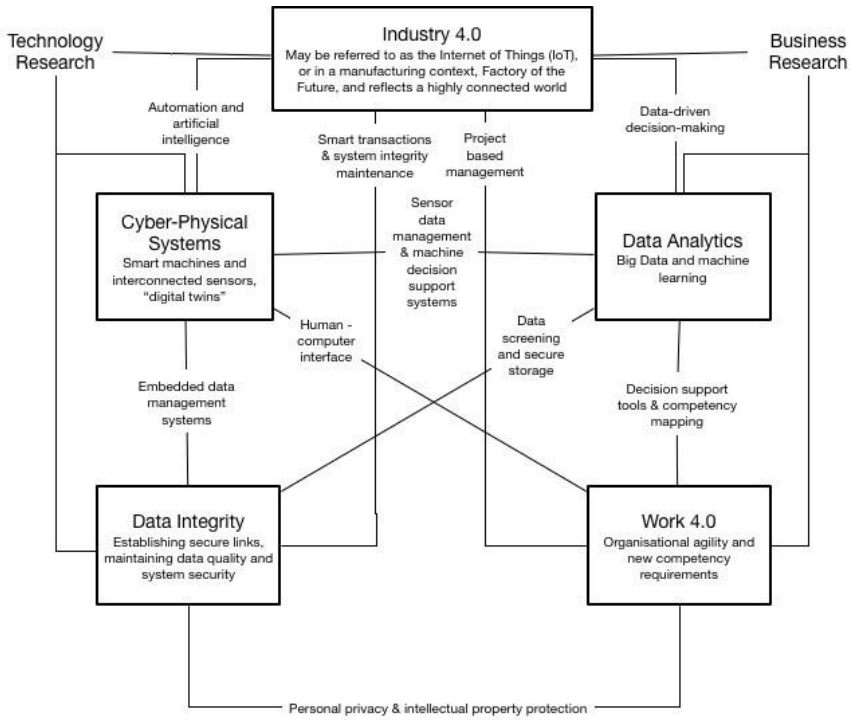

Figure 1. A system view of Industry 4.0 (source: [27]).

According to Figure 1, realisation of X4.0 requires the integration of four subsystems: cyber-physical systems, work 4.0, data analytics and data integrity. Hence, cyber-physical systems can be mapped to product product element and the work 4.0 system can be mapped to people element. Mapping of data analytic, data integrity and all interconnections may be viewed as a process element supporting the 3P interactions. This structure can form an initial conceptual X4.0 implementation among the companies involved in the X paradigm. Adopting an interacting network-centric system of systems view brings focus on decision-making either in responding to an emergency or in organizing alternative ways to meet customer requirements.

3. System of Systems View of X4.0 in Transdisciplinary System

From this view of Industry 4.0, it can be conceptualised that X4.0 is an elaboration of generically similar systems – a paradigm that exhibits a focus on cyber-physical, big data and engineering data analytics which will share similar characteristics with other businesses with the same focus.

3.1. System of Systems View

A generic system could be represented as the coalition of three elements: people, process and product, in an operating environment. The 3PE model has been used in a quantitative sense focusing on assessing risks in engineering projects [28]. The product element in the 3PE model is the tangible hardware / software element that can give the "touch-and-feel". The people element includes all human participants to enable successful operation of the system. To use the product properly, a set of procedures, i.e. process, should be defined and followed. Needless to say, these elements are interacting among themselves. Without interactions, the product is not used by people, the people do not follow the process, the reaction of the product is unpredictable without a defined process. The 3PE model represents a standalone system in its system's environment.

Expanding from the single 3PE model as the fundamental system unit, Cook and Mo [29] represented the alliance, a consortium of companies engaged in a large defence project, as a system of systems as shown in Figure 2. It is necessary to note that only two organisations are drawn as illustration only.

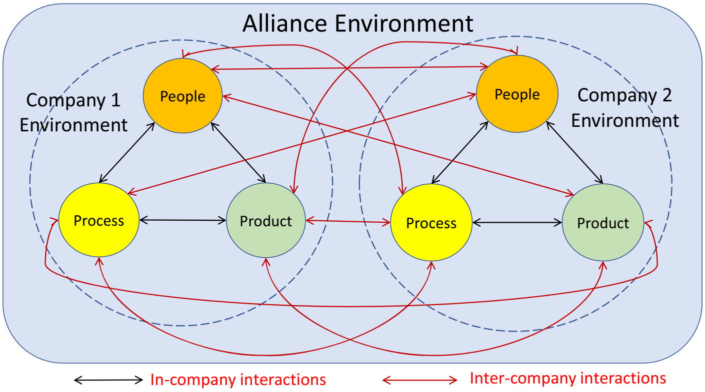

Figure 2. Alliance map with two partner organisations.

With X4.0 superimposed on top of the system of systems model, network-centric operations are about making connections and sharing information, i.e. interactions. Whilst frequent and recurring events may be described in terms of structured flows, it is the actors (people) who are driving the system's performance. For example, property management firms have operated tenant transaction systems for decades on web browser, e.g. collection of rents, distribution of payments to vendors, management of leases. The system of systems in this case should include network monitoring and control system for novice users who are unable to respond to disruption.

3.2. Characteristics of a Transdisciplinary System

The concept of transdisciplinary system has been explored as an extension of successful concurrent engineering practice that promotes innovative thinking and process. Sobolewski [30] presented a model of amorphous transdisciplinary compound service system that comprised micro-services and macro-services from multiple service providers. The transdisciplinary operating system provided amorphous front-end macro-services with corresponding collaborations of back-end service providers. The transdisciplinary process has been developed to solve ill-defined and socially relevant problems. In particular, implications for engineering research, practice and education have been investigated under transdisciplinary engineering banner [31].

In general, a transdisciplinary system is a complex system and can be conceptual modelled as a number of linked processes. It exhibits system characteristics in organisational, societal, cultural, and the usual engineering system structures that requires governance arrangements spanning multiple boundaries and comprises hierarchy between people, processes and products in a collaborative way [32].

With the X4.0 in place, the two evolutionary systems within the transdisciplinary system, viz, transdisciplinary development system and product service system are inevitably migrating onto IoT platforms. It would then be logical to think of incorporating a X4.0 system into each of the evolutionary systems as shown in Figure 3. The two evolutionary systems are not in conflict to each other. They exist at different times of the evolution lifecycle.

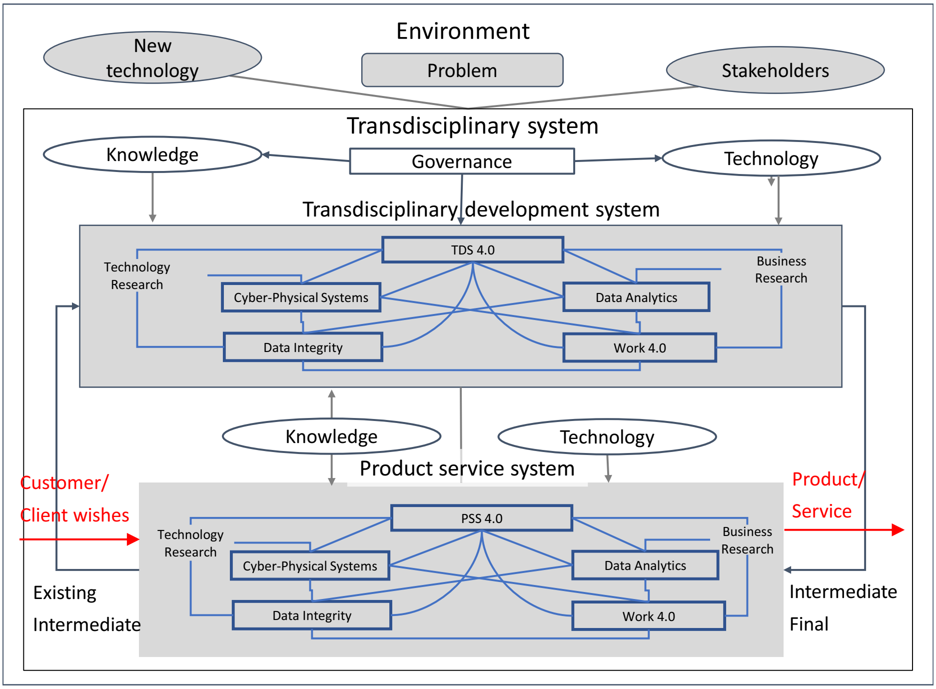

Figure 3. Adapted transdisciplinary engineering system model with X4.0.

The core activities of transdisciplinary development targets system that consists of multiple subsystems. The development subsystems form a coalition of different disciplines, social as well as technical, that are needed to solve the problem. The outcome is a product service system (PSS) that satisfies customer requirements. Within these evolutionary processes, the use of X4.0 related practices and facilities would greatly enhance communication and effectiveness of the transdisciplinary teams.

X4.0 paradigms are still evolving, and so are transdisciplinary systems. The forms and procedures differ significantly among different industries. It is still early to cite real examples of such systems. However, a close enough example has been reported two years ago [33]. A new internet based company Blamey Saunders Hears has gone through transdisciplinary development in a technology cluster precinct in collaboration with a similar company via internet. The outcome is a PSS of hearing aid products and services via IoT connection with experts. The authors also concluded that adopting a standard system design structure helped to define protocols in the system and streamline operations of the system significantly.

4. Conclusion

This paper reviews the fundamental requirements of X4.0 implementation within any industry paradigm X, where the instantiation of X is expanding in different industry sectors around the world. By examining the characteristics of currently known fourth generation (i.e. 4.0) paradigms such as Quality 4.0, Water 4.0, Procurement 4.0, Oil and Gas 4.0, etc. it is realised that the use of IoT is immersive among the participants. The powerful communication platform facilitates socio-technical interactions and accumulates large amount of data in its operation.

The X4.0 system of systems structure is proposed with functional blocks cyber-physical system, data analytic, data integrity and work 4.0, and within each block we consider associated product, process and people roles in delivering requisite functionality. Based on this building block, it is conceptualised in this research that a X4.0 system can be the key platform of an evolutionary process of a transdisciplinary system in which the transdisciplinary development can be facilitated efficiently on IoT. As the transdisciplinary development progresses, the development outcome in the form of PSS can easily move to the operational stage to achieve the goal of customer satisfaction.

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Mapping the Competencies of Design Engineers Against the Jantsch's Hierarchical System

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Abstract. Presented in this paper are the results of a systematic literature review to identify the competencies required by design engineers to work in increasingly complex societal projects. These competencies are then mapped against the four levels of a hierarchical system defined by Jantsch to ascertain the disciplinarity of these competencies. The results from this mapping form the first phase in the creation of a Designer Readiness Level for transdisciplinary engineering. To date current research has identified that to meet these future needs, defined as Grand Challenges for Engineering by the National Academy of Engineering, it will be necessary to adopt transdisciplinary methods of working. However, there is little in the literature that identifies how to assess the transdisciplinarity of people, tools or project teams. Although literature and learned societies do highlight that engineers are crucial to meet these societal needs, how do we determine whether an engineer is able to work in a transdisciplinary manner? A total of 2398 papers were included in the review and twenty-nine papers selected for full-text review. A final seven focussing on practicing design engineers were used to create a current list of competencies. The paper continues by describing the analysis method and results of mapping the competencies identified against Jantsch's four levels. The paper concludes with a summary of the next stage required to create a Designer Readiness Level for transdisciplinary engineering.

Keywords. Transdisciplinarity, Transdisciplinary Research, Transdisciplinary Engineering Research, Design Engineer, Competencies

Introduction

As the global population grows, concerns about environmental issues and the unsustainable use of the world's resources are increasing [1, 2]. The National Academy of Engineering (NAE) committee in 2012 identified 14 Grand Challenges for Engineering which are critical to sustaining continuous advancement of humanity e.g. make solar energy economical, engineer better medicines, provide energy from fusion. With engineers being integral to creating innovative products that improve quality of life [3] and advance society in a sustainable way [1]. These grand challenges can be defined as complex problems that require involvement of a wide range of stakeholders [3].

A transdisciplinary (TD) approach is hypothesised to offer a higher level of analysis compared to other disciplinarities [4] and hence may well be the right approach to tackle complex engineering challenges. TD has already been used in context of "wicked" -

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large, complex and ill-defined problems that require involvement from a range of disciplines working towards a common goal [5]. In order to achieve societally focused or transdisciplinary engineering (TE), design engineers will require the dynamic acquisition of specific competencies.

The competencies design engineers may require for TE is the focus of this paper. The aim of the review and secondary analysis is to compile and map competencies to identify if any are more required for TE. To do this we answer, three research questions:

RQ1. What evidence is in the literature regarding competencies related to design engineers?
RQ2. Can these identified competencies be classified into disciplinary competencies?
RQ3. Do any of the identified competencies have TD attributes?

The paper is structured as follows: section 1 provides a motivation for selecting competencies related to design engineers. In section 2, Jantsch's TD hierarchical system providing the framework for this study is described. A methodology follows in section 3; with the results being presented in section 4. A competence classification model is then proposed in section 5; this is followed by a discussion in section 6. Finally, the implications of the results and future research are discussed in the conclusion.

1. Design Engineers and Competencies

Blessing, Pahl and Wallace [6] use the terms designer, design and development engineer interchangeably to describe engineers involved in the creative aspects of a product life cycle, in the context of this study we use term design engineer. Much of engineering design research has sought to understand how engineers spend their time, with traditional thought being that engineers are purely technical with 100% of their time allocated within steps of the design process. Whereas later research found that technical work only takes up 47% of a typical designer's time [7], and that while technical competencies are important, they are inseparable from social competencies linked to effective collaboration [8].

Since designers are increasingly more often collaborating in design activities using complex working environments involving a variety of different actors and cultures [9] they are hence relying on a range of non-technical skills in particular, communication [8]. Other collaboration skills such as team-working skills, intercultural communication and knowledge management are becoming indispensable.

The definition of the term competency used in this paper refers to a capacity to effectively perform both task and role and is linked to the individual's skills, knowledge, motives, values and personal traits [7, 10].

While a large body of research focuses on competency requirements of engineers [7, 8] , there is a lack of studies specifically focusing on design engineers [7], even though it is estimated that over 70% of the product development life-cycle cost is embedded in the design conception phase [11]. It is also notable that a large part of engineering competence literature focuses upon engineering education, specifically to close gaps between skills acquired in higher education and skills required by industry [8, 12]. However, to make an effective TD design engineer it will require competencies beyond those acquired in higher education, and will require a life-long professional development in order to deal with evolving challenges linked to TD projects [5].

Predicting the competencies required by future design engineers to be able to work in a TE manner provides a significant design engineering research opportunity and is the purpose of the author's PhD. To enable this, we require a structured approach to classify the disciplinarity of engineering competencies.

2. Jantsch's TD System

The TD term was first proposed by Jantsch at a conference in 1970, as a hierarchical multi-level, multi-goal education and innovation framework, for an education system [13]. This was chosen to map a designer's competencies because the framework is the original TD model [14] and can be operationalised [15]. The framework (Figure 1) consists of four levels: empirical, pragmatic, normative and purposive. The base of the pyramid is the empirical level, composed of individual scientific disciplines i.e. physics. The pragmatic level contains applied sciences, where theories from the empirical level are applied in individual disciplines i.e. engineering. Above this is the normative level which represents social systems constructs such as norms, laws and regulations. At the top of the pyramid, sits the purposive level with societal values and meanings.

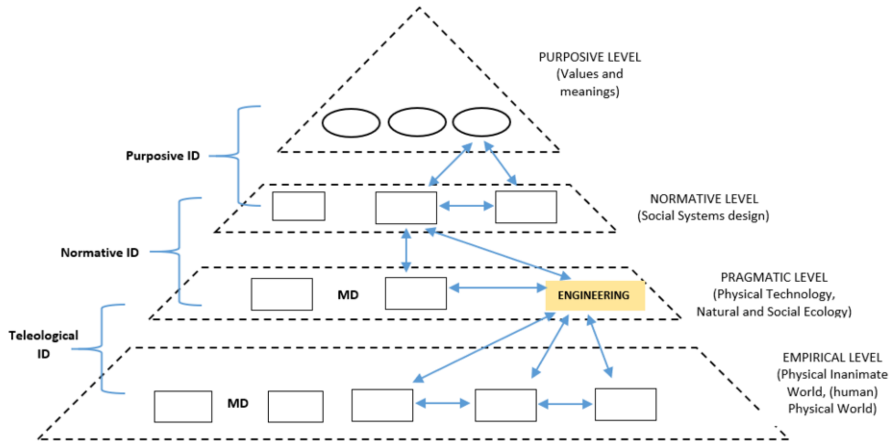
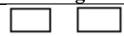
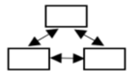
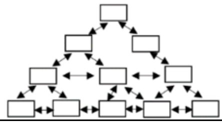


Figure 1. Multi-level, multi-goal, hierarchical system adapted from [13].

Different types of co-ordination and co-operation take place across the levels, involving the interaction of different actors. Jantsch defines five disciplinary ways of co-operation and co-ordination: multidisciplinarity (MD), pluridisciplinarity, crossdisciplinarity, interdisciplinarity (ID) and transdisciplinarity (TD). He further divides ID into teleological ID, normative ID and purposive ID, to describe the levels amongst which they interact (shown in Figure 1).

Table 1 defines and illustrates the interactions in disciplinarities, where TD is deemed the highest level of disciplinarity. In TD all levels of the system interact together, with all disciplines and interdisciplines, being co-ordinated in a top-down manner from the purposive level to pursue a common system goal [13]. Each disciplinarity shown refers to a distinct disciplinary organisation and way of working. We argue that by asking questions based on the definition of each level, it is possible to identify and link specific competencies to each level.

Table 1. Jantsch's definitions of disciplinarity.

Disciplinarity	Definition	System configuration
Multi, pluri and crossdisciplinarity (MD)*	One level, variety of disciplines, no co-operation	
Interdisciplinarity	A common axiomatics for a group of related disciplinas is defined at the next higher hierarchical level or sub-level, thereby introducing a sense of purpose	
Transdisciplinarity	The co-ordination of all disciplines and interdisciplines in the education/innovation system on the basis of a generalized axiomatics (introduced from the purposive level) and an emerging epistemological pattern	

(*) Within this paper MD for the purpose of mapping encompasses pluri, cross and multidisciplinarity

Section 3 provides the methodology for identifying the relevant literature to find evidence regarding competencies relevant to design engineers.

3. Methodology

The aim of this research was to identify and characterise, in disciplinary terms, the design engineers' competencies within published literature. The review strategy follows the steps of a systematic literature review (SLR) process outlined by Tranfield [16]. As a part of this process the authors formed a review panel to recommend relevant literature, formulate research questions and make literature inclusion/exclusion decisions [16].

An initial exploratory investigation of research related to engineer's competencies elicited the terms "engineer", "competence" and "skill", being expanded to the following keyword selection for searching literature: competence, ability, skill, capability, behaviour, knowledge and attitude in title, abstract and keywords (Table 2).

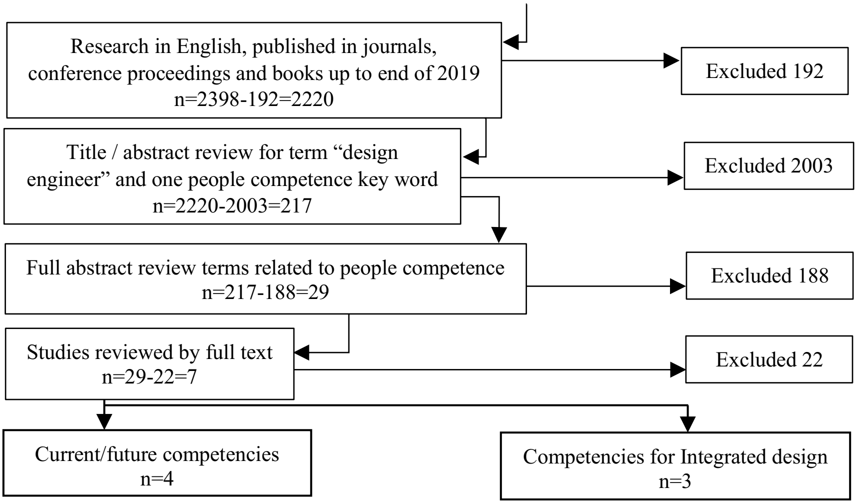
Table 2. Search strategy.

"Design engineer"
AND
competenc* OR abilit* OR *skill* OR *capabilit** OR *behaviour* OR *knowledge* OR *attitude*

There are limitations to using specific keywords or single literature databases. Using the term "design engineer" may miss some literature not explicitly using this term, however, it is necessary due to the large volume of results to adopt a pragmatic approach to the inclusion of appropriate search term and literature resources. The electronic database SCOPUS was selected as it provides a characteristic sample of broad trends in research and covers a wider range of publications compared to the Web of Science [17]. The search resulted in a total of 2398 documents encompassing a broad range of literature from sciences, energy, social sciences to business, management and accounting due to the current ID nature of engineering research [6, 8]. As per Tranfield [16], the different phases of the SLR are summarised in the process flow diagram in Table 3.

Table 3. Literature search process.

Scopus keyword literature search results
n=2398



Seven papers addressing specific competence or skill profiles related to design engineers were relevant to our analysis. Based on their research focus they were classified into two categories (Table 3), four studies S1, S2, S6 and S7 focus on current or future competencies and studies S3, S4 and S5 focus on integrated design competencies in relation to the European certification scheme (Table 4).

Table 4. Literature Focus.

Study	Focus	Reference
S1	Future competency profile	Robinson et al., 2005[7]
S2	Current competencies - Knowledge classification	Ahmed, 2007[10]
S3	Integrated design competencies	Riel et al., 2009[18]
S4	Integrated design competencies	Riel et al., 2010 [19]
S5	Integrated design competencies	Riel et al., 2012 [11]
S6	Current competency profile	Abbas et al., 2013 [12]
S7	Current competencies - Innovation competencies	Birdi, Leach and Magadley, 2016 [20]

To provide a systematic approach to analysing qualitative data, the thematic analysis method allowed for integration of competency data from the seven papers for further analysis [21]. Based on the way the data was provided the data extraction methods vary [21]. Data in papers S1, S5, S6 were extracted using a semantic approach directly from listed competency profiles. Data were extracted using a latent approach from text only in S3, S4 and S7. While, in S2 data was identified using a mix of both approaches.

4. Results

Paper S1 used a three-phase methodology to compile a list of 42 future competencies divided into six groups. S2 is an empirical study classifying types of knowledge and the time it takes to become an expert in a competence. The paper focuses on procedural knowledge and does not list all identified types of knowledge, with only twelve explicitly listed. In addition, eight personal attributes were identified, and another 18 skills were extracted from the text. S3, S4 and S5 are a series of studies concerned with life-long learning, they examine integrated design competencies in order to create industry driven training for European Certificates and the Qualification Association. S6 identifies 75 competencies required by design engineers in Pakistan and describes a competency development and enhancement model. S7 is a qualitative study of 169 design engineers examining the relationship of individual competencies and innovative behaviour.

The papers were published between 2005 and 2016, which may not relate closely to important current competencies as even the most recent is 4 years old. The S1 study from 2005 provides future competency profiles looking ten years into the future placing it into 2015. Compared to S6's 2013 competency profile which identifies more competencies, both produce very similar competencies, meaning that S1's futuristic view could be deemed a good representation.

Interestingly IT skills are only discussed in the oldest study S1 and this is only generically. It is notable as literature identifies a growing need for competencies related to digital technologies that will allow engineers to work with networked manufacturing technologies in automated environments; as well as analyse and understand large volumes of complex data produced by these automated environments [5, 22].

Each study provides a different depth of detail when describing competencies from very generic in S1 to a more detailed contextual description in S5. According to Ahmed [10] competencies must have a context thus those competencies with more detail provide richer data for the next stage of analysis. The competencies from seven papers were compiled to a profile containing 117 competencies divided into several groups such as personal attributes, cognitive strategies, technical skills, communication and collaboration competencies. To answer RQ2 and RQ3 these 117 competencies were individually mapped against the TD framework.

5. Mapping competencies against the Jantsch's hierarchical system

In order to map designer competencies according to different types of co-ordination as illustrated in Figure 1, we describe what working at each level would look like for design engineers based on Jantsch's definitions. A model for classifying disciplinary competencies is proposed in Table 5, by formulating two questions for each level of working to describe the nature of interactions.

Engineering design as an applied science sits within the pragmatic level and interacts with sciences at the empirical level (Jantsch defines as teleological ID). Competencies related to Jantsch's definition of teleological ID are linked to the capitalisation of scientific knowledge from an empirical level and applying this to engineering tasks. Thus, by asking two question related to teleological ID as presented in Table 5 these types of competences can be identified.

Table 5. Competence classification method.

Multidisciplinarity	Teleological Interdisciplinarity	Normative Interdisciplinarity	Transdisciplinarity	General competencies
Is the competence necessary for working in disciplinary isolation?	Does the competence enable capitalization of scientific knowledge from empirical level?	Does the competence demonstrate knowledge of rule and norms?	Does the competence demonstrate purpose consideration?	Is the competence necessary for working in any job?
Does the competence enable awareness or experience of other disciplines without	Is the competence necessary for working in engineering	Does the competence enable working with experts from other disciplines/	Does the competence demonstrate value recognitions?	Would the competence be in a job description for most jobs?

integration of knowledge?	discipline on engineering task?	stakeholders from outside science?

MD relates to a design engineer working within the engineering discipline, in isolation from other applied disciplines. They may have experience or awareness of other departments or disciplines, but that knowledge does not translate to their work. In practice it requires mostly the same competencies as teleological ID.

Normative ID refers to engineering interacting with other applied sciences on the pragmatic level while adhering to norms, rules and policies set at the higher - normative level. It includes design engineers whose role is the development of technological alternatives e.g. innovative technology. Competencies relevant to this level of working cross the normative level boundary and allow design engineers to co-operate with a wide range of stakeholders and recognise different points of view and requirements.

Purposive ID only crosses normative and purposive levels without integrating scientific disciplines, thus is not applicable to engineering. The TD level can be achieved by integrating all other levels: it is about the interactions up and down and across all levels of the pyramid; between disciplines, across project boundaries, between academia and industry while the purpose is incorporated across all levels of the pyramid. Competencies relevant to TD will enable the integration of requirements and values of different stakeholders by recognising the purpose.

Table 6: Disciplinary competencies.

Teleological Interdisciplinary competence (33)	**Normative Interdisciplinary competence (26)**	**Transdisciplinary competence (5)**
The ability to interact successfully in distributed teams	The ability to acquire information from stakeholders from different cultures	The ability to collect and implement requirements of all stakeholders into the product
Dealing with paradox	Cope with complexity	Thinking from product-use point not solutions
Critical thinking	Concern for community	Design for service
Abstract thinking	Ability to understand domain experts	Managing multiple multi-disciplinary projects
Analytical abilities to evaluate worth of an idea	Ability to translate domain experts' requirement into their design task	Design of major complex facilities
Ability to generate multiple alternative solutions	Negotiation skills–to persuade others of idea worthiness	
Uses latest engineering processes, methods and tools	Higher degree of business understanding	
Applies engineering knowledge	Understanding economical aspects of product's total life	
Technically versatile	Marketing aspects	
Knowledge of product lifecycle	Understand competition	
Ability to contribute to design of major projects	General knowledge of ethics, politics, mission	
Manufacturing process knowledge	Relevant environmental requirements	
Process moderation	Ability to communicate with non-engineers	
Value improvement	Customer focus	
Requirements and resources management	Effective communication at all levels	
Intrinsic motivation to innovate	Representation of the design solutions for different actors' views	
Tendency to work alone	Knowledge and compliance with codes and standards	
Focus creativity purely on technical aspects	Ability to communicate with specialists from different fields of sciences (find the common language for better understanding one another)	
Ability to close/complete a project/process, ability to share ideas, data, knowledge in order to be able to make design decision collectively	Ability to communicate with specialists from different cultures	
Expertise		
Capitalization of knowledge (effective retrieval)		

Ability to lead in an engineering discipline Formalization of knowledge-using right methods to capture knowledge Professional ethics Ability to interact successfully in distributed teams Memories of previous projects Ability to use tools for collaborative design Coordination among groups and teams	(avoid misunderstanding, miscommunication) Awareness that integrated stakeholders have different expectation, preferences and constraints Intercultural skills required for essential entities to be integrated into the holistic design process as a prerequisite to understand different approaches

This model assisted with finding disciplinary competencies (Table 6) to answer RQ3, by answering yes or no to one or both questions. In summary we found three MD competencies, 33 Teleological ID competencies, 26 Normative ID competencies and five TD competencies. The remaining 50 competencies have no disciplinarity or lack context and hence were unable to be clearly classified based on disciplines.

6. Discussion

We answered RQ2 and identified competencies based on disciplinarity. Mapping identified three MD competencies: manage multi-disciplinary teams; understanding organisational dynamics and central/head office experience. They relate to awareness or experience of other departments within their own organisation, but without co-operation or integration of the knowledge.

The largest group is Teleological ID competencies. This is not surprising as this group represents competencies related to technical aspects of the design engineer's role. By asking "Is competence necessary for working in the engineering discipline on engineering tasks?" we were able to map all technical and design process skills to this level. Other competencies related to design task include cognitive abilities such as critical thinking, abstract thinking, and analytical abilities to evaluate an idea.

The second largest group are Normative ID competencies. Included competencies focus on awareness of different stakeholders, knowledge of the wider business environment and knowledge and compliance with codes and standards. One competence describes a tendency to work alone, focusing creativity purely on technical aspects, such preference can be a good indication if the person is suitable to work in TD manner.

Asking "Is purpose / value considered?"; "Does competence demonstrate purpose / value recognition?" helped to answer RQ3 and identify five TD competencies shown in Table 6. The first two competencies relate to an engineer's ability to think from a stakeholder perspective, how and for what purpose they use a product/service, and what value are they getting from its use. The third competence implies awareness of other stakeholders' requirements, but only by implementing these requirements the purpose is recognised. Competencies four and five imply understanding of complexity, purpose and value of the project.

The group of generic competencies include mainly personal attributes, cognitive strategies and abilities, but also basic communication competencies. Although, they are important to design engineering, they relate to basic skills relevant to any job. Competencies include self-motivation, personal honesty, career ambition and ability to adapt to change.

Although mapping decisions mentioned above are subjective and interpretations of competencies may vary, what is clear from this analysis is that the context is important for disciplinary classification. For instance, general competence inter-cultural communication, with context translates to disciplinary competence at all levels (first entry in Table 6).

The TE working relates to collaboration of a range of stakeholders on a complex problem that cannot be solved by a single discipline, with purpose considered across all levels. This indicates that in order for engineers to work in this way normative ID competencies are important such as, the ability to communicate and co-operate with a range of stakeholders from outside sciences and across different cultures, understanding self and the wider societal environments, and understanding different points of view. But what takes competencies to the TD level is the ability to consider the range of values and integrate these into the solution. This may require the change of thinking in order to incorporate purpose and value into design engineer's work.

7. Conclusion

This paper presents the results of an SLR to identify competencies required by design engineers. The review demonstrates that although the role of design engineers is crucial to the product development process and to meet future societal needs, there is a gap in current designer competency profiles. The first phase in the creation of a Designer Readiness Level for transdisciplinary working was to map the identified competencies against the levels of the Jantsch's hierarchical framework. The results from this mapping show that while many competencies lack context making it difficult to classify, five competencies were found showing TD attributes and 26 competencies showing normative ID attributes. This is important when thinking of competency requirements for future TE projects. Education and training for design engineers will need to reflect this necessity to acquire not only TD competencies but also competencies related to the collaboration with a range of stakeholders from outside sciences and across different cultures as well as understanding the self and the wider societal environments. The focus of future research and the next step in the creation of a Designer Readiness Level will be to determine the way to measure current competency levels against TE competency requirements for TE projects in order to identify gaps in training and curricula requirements.

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Transdisciplinary Engineering for Complex Socio-technical Systems – Real-life Applications
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Classifying the Disciplinarity of Engineering Academic Literature

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Abstract. Based on the appearance of the term within the academic literature, it would appear that transdisciplinarity (TD) approaches are receiving increased research attention. However, the literature suggests a lack of consensus over how TD is defined and classified. This could give rise to inconsistency and papers that claim to be TD which are not, and alternatively papers that fail to mention TD but which might be classified as such. This is significant and creates a challenge in identifying the true level of TD research. This work contributes towards understanding the state of TD within engineering. Explicitly, we address the research question: Is the engineering academic literature claiming to be TD, actually TD? Within this study we operationalise the work of Jantsch and use this as a means to classify the disciplinarity of 177 engineering journal papers which reference TD within their abstract. The results show only 24% to be TD. The majority (64%) are classified as interdisciplinary. Conclusions find that to improve consistency, a clear definition and rules for differentiation between TD and ID research are required. Future work calls for: (1) comparative studies which apply different methods for assessing disciplinarity across the dataset used within this study and which use the method employed within this study across different fields. (2) Research to analyse whether TD working is being undertaken in engineering without it being referenced within the paper.

Keywords. Transdisciplinary, Trans-disciplinarity, Disciplinarity, Transdisciplinary Engineering, Content Analysis.

Introduction

Contemporary engineering products and systems are getting evermore interconnected with multiple disciplines and stakeholders involved in all aspects of the lifecycle [1, 2]. This complexity necessitates a need to move away from a traditional reductionist discipline-based approach, to go above and beyond the disciplinary boundaries. That is, there is a need for transdisciplinary engineering (TE) approaches. However, despite engineering being a designated field for transdisciplinarity (TD) a recent study suggests that compared to interdisciplinary (ID) and multidisciplinary (MD) approaches, the penetration of TD is low [3].

Although providing a view of the use of TD within engineering, the work of Lattanzio, Carey [3] presents a certain perspective. That is, the analysis uses the appearance of the terms MD, ID, TD within the engineering papers. It does not look to further examine whether the papers conform to any particular definition of these terms.

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One of challenges with understanding the use of TD within engineering is the loose way the term is used. Broadly, TD has been defined as ‘a research approach that includes multiple scientific disciplines (interdisciplinarity) focusing on shared problems and the active input of practitioners from outside academia’ [4]. However, both across and within the different academic fields a plurality of definitions of TD persist [5]. This has resulted in a situation whereby what one author considers TD might be considered a different level of disciplinary by another [5]. Adding to this challenge is that funders are starting to call for research to be using a TD approach [6]. Potentially, this inconsistency in definition, coupled with the evolving “fashion” for TD work, could result in a situation whereby research claiming to be TD does not meet all, or indeed, any of the existing definitions of the term.

This study aims to contribute towards understanding the state of TD within engineering academic research by answering the research question: *Is the engineering academic literature claiming to be TD, actually TD?*

The paper is structured as follows: First, the background literature. Within this section the seminal work of Jantsch [7] which provides the underpinning theoretical framework for this study is introduced (Section 1). Following, the research approach is described in detail (Section 2). The approach involves the creation of a coding agenda which can be used to classify research disciplinarity. This coding agenda is applied to the academic engineering literature which references TD within the abstract. The results are presented (Section 3), and discussed (Section 4). Finally, conclusions are formulated (Section 5), limitations identified (Section 6) and future research work recommended (Section 7).

1. Background

It is generally accepted that the origins of TD date back to the 1970s and the original work of Jantsch [7]. Within this work Jantsch asserts that for education and innovation to be of value to society it needs to cut across the social, economic, political, technological, psychological, anthropological and other dimensions. Using a holistic approach, Jantsch defines a hierarchical framework that identifies key levels for consideration within a multi-level, multi-goal education and innovation system (Figure 1).

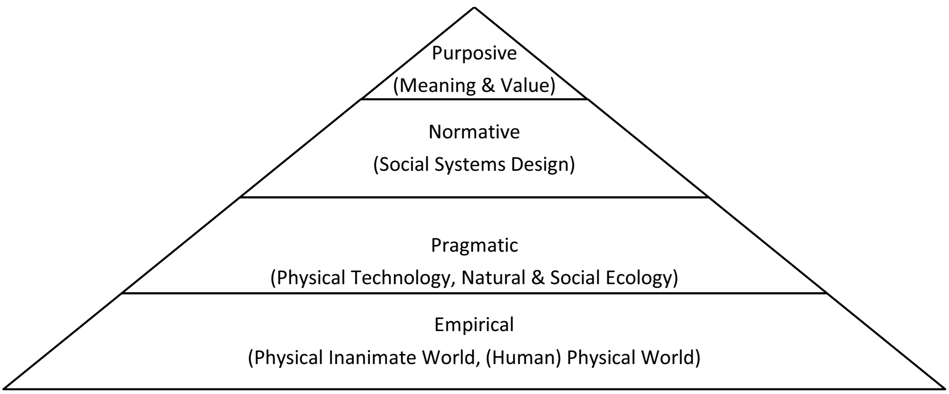

Figure 1. Adapted version of Jantsch’s education/innovation system [7].

Building on this framework, Jantsch defined six disciplinarity levels: monodisciplinarity, multidisciplinarity, pluridisciplinarity, crossdisciplinarity, interdisciplinarity, and transdisciplinarity. These definitions are constructed based on differences in cooperation and coordination within and across the purposive, normative, pragmatic and empirical levels.

Although the creator of the original framework, Jantsch's conceptualisation has not been universally accepted. To-date, there are a pluality of approaches proposed to differentiate between disciplinary levels [8-12]. The inconsistency is compounded by the evolution from simple, abstract categorisations, to typologies which acknowledge the nuances and complexity within each of the disciplinary states [13]. As an example, Bruun, Hukkinen [14] subdivide multi- and interdisciplinarity into encyclopedic MD, contextualizing MD, composite MD, empirical ID, methodological ID, theoretical ID. The lack of consensus would suggest that although papers may claim to be TD, their classification is dependent upon the definition applied.

Whilst a number of conceptual approaches for assessing disciplinarity exist there have been few attempts to apply these to characterise the disciplinarity of research efforts, and thus there is no universally accepted approach to classifying the disciplinarity of academic engineering literature [13]. Within this work we address this gap by operationalising the work of Jantsch, creating a coding agenda and applying it to academic engineering literature.

2. Research approach

The aim of this study was to contribute to understanding how TD approaches are being used within engineering academic research. This research assesses the disciplinary level of engineering academic literature which appears to be TD, to see if it meets the definition of TD as proposed by Jantsch. The approach used within this research is illustrated by Figure 2.

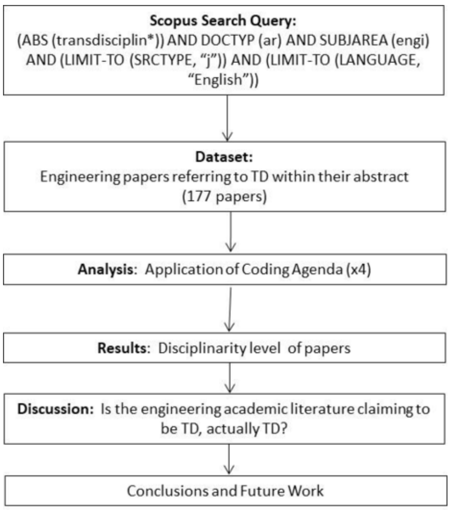

Figure 2. Research approach.

The dataset used within this study was extracted from Scopus. Scopus was considered preferential to Web of Science as it provided 20% more coverage and incorporated a wider range of journals [15]. The dataset was limited to papers which Scopus identified as falling with the engineering subject area, with the term “transdiscipl*” within the abstract. This is used as a proxy for work claiming to be TD. The search uses the wildcard “*” to capture any possible ending of this term e.g. transdiscipline, transdisciplinary, transdisciplinarity. To ensure a level of quality the search was constrained to peer-reviewed journal articles, and for accessibility those written in English. Applying this search 177 papers were returned.
A coding agenda (described in Section 2.1), was used to analyse the abstracts and assess their level of disciplinarity.

2.1. Coding Agenda

Key to understand the extent that TD approaches are being used within engineering academic research is having a consistent way to classify disciplinarity. To achieve this a coding agenda was created which operationalised the work of Jantsch [7, 16]. The rationale for using Jantsch is that to date there is no consensus on how to classify disciplinarity. An originator of the field, the work of Jantsch provides a framework which can be operationalised into an approach which is both complete and practical.

A coding agenda contains the rules which are used to apply a classification. To create a coding agenda, artefacts (i.e. documents, audio recordings, video) are anlaysed. A wide range of theoretical frameworks and techniques have been proposed to undertake content analysis [17-20]. Within this work we follow the steps defined by Mayring [19]. The rationale for this choice is that the steps offer a structured and repeatable process (Figure 3).

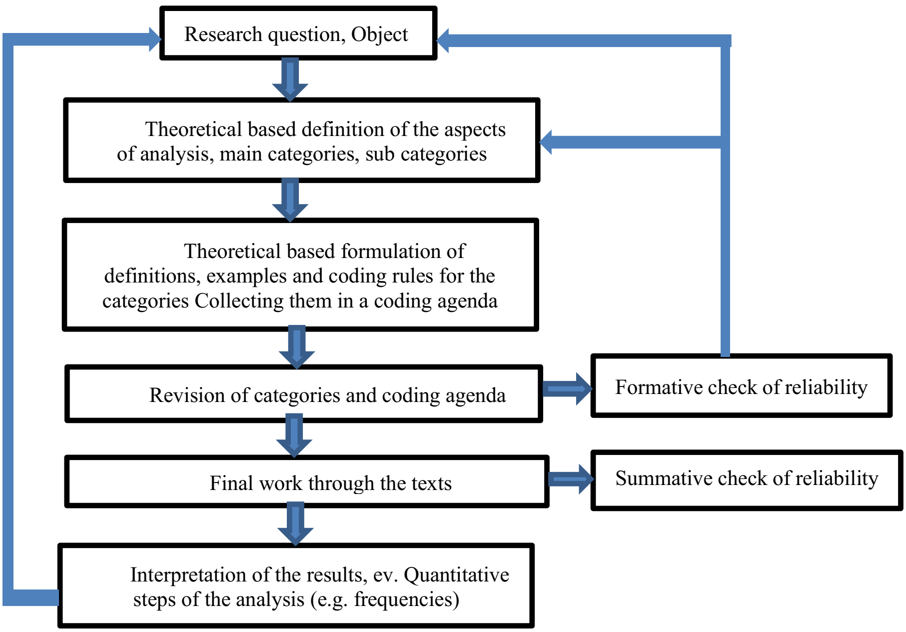

Figure 3. Step model of deductive category application. Adapted from Mayring [19].

The outputs of the content analysis informed the creation of the disciplinary coding agenda presented in Table 1.

Table 1. Disciplinary coding agenda.

Category	Definition of Jantsch	Coding rules
Monodisciplinary (M)	Specialisation in isolation. One-level, single-goal; no co-operation.	Research related to one level of Jantsch's framework – one discipline. No involvement of practical engineers. No reference to a broader research application scope and relation to other disciplines. No reference to stakeholders at the normative level.
Multi, Pluri, Crossdisciplinary (MD*)	No cooperation; cooperation without coordination; rigid polarisation towards specific mondisciplinary concept. One-level, multi-goal, cooperation (but no coordination)	Combines approaches from different disciplines, but no specific indication of a coordination by a higher-level concept.
Interdisciplinary (ID)	Coordination by higher level concept. Two-level, multi-goal; coordination from a higher level.	At least two levels of Jantsch's framework are involved. Methods and approaches of at least two disciplines are mentioned in the abstract and the disciplines' approaches are coordinated by higher-level research or innovation concept.
Transdisciplinary (TD)	Multilevel coordination of entire education/innovation system. Multi-level multi-goal; coordination toward a common system purpose.	All four levels of Jantsch's research and innovation system should be present: Explict consideration of societal meaning and value. Collaboration with stakeholders at the normative level. Involvement of more than one discipline at the pragmatic/empirical levels.

(*) Within this paper we use Multi to denote that for our coding Multi* encompasses Pluri-, Cross- and multidisciplinarity.*

The coding agenda contains three columns: *Category, Definition of Jantsch, Coding rules*. The *Category* is the classification which is applied within the analysis. It should be noted that within this paper we have used the term Multi* (MD*) to encompass pluri-, cross- and multidisciplinary papers. This approach was used because the nuances that separate the three terms would be difficult to identify from an abstract, and provide a level of detail which is not required to address the research question. The second column provides the definitions of Jantsch taken from the original works [7, 16]. Finally, the third column details the coding rules against which classifications are made.

When conducting the analysis the coding agenda was applied to each abstract within the dataset. Within the literature a number of ways have been suggested to improve the reliability of coding. These include increasing the numbers of individuals coding the data, choosing coders familiar with the constructs to be identified, and training coders in systematic practice sessions [13, 21]. Within this work two strategies were adopted: 1. Coding was undertaken by four Research Associates with previous exposure to the work of Jantsch. The eventual classification made was the mode of the four responses. If no mode arose from the coded abstracts the coders were given the opportunity to first discuss, and where they considered appropriate, adjust their individual response. Through this means consensus was achieved. 2. Prior to commencing coding a training set of 50 papers was used as a means through which to improve coder calibaration.

3. Results[2]

Though no time period was set, analysis of the 177 papers within the dataset showed them to have been produced over the period 1980 – 2018, with accelerated growth seen from 2000 onwards (Figure 4). This supports that over recent years a greater number of engineering journal papers are using the term TD.

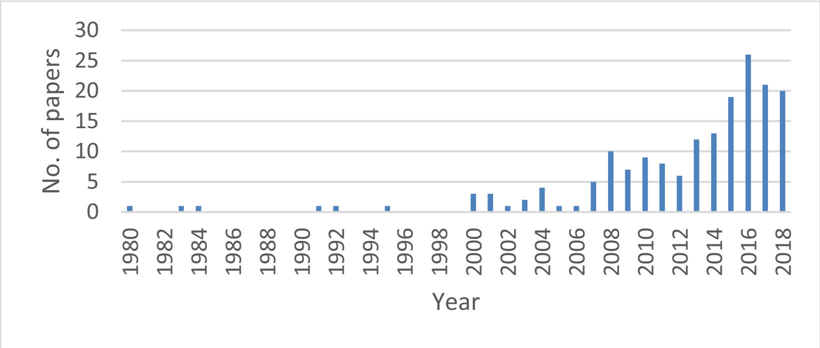

Figure 4. Engineering papers with "Transdisciplin*" with their abstract, extracted from Scopus 25/3/2019.

Of the 177, three papers were excluded because they were not research contributions, but rather informal essays or publication volume descriptions. The coding agenda was applied to the remaining 174 abstracts in order to analyse their level of disciplinarity.

The results of the analysis are presented in Figure 5. This shows that of the 174 papers less than a quarter (24%) meet the definition of TD. A total of 111 of the abstracts are classified as ID (64%), with 11% classified as MD*. No papers were categorised as monodisciplinary (M).

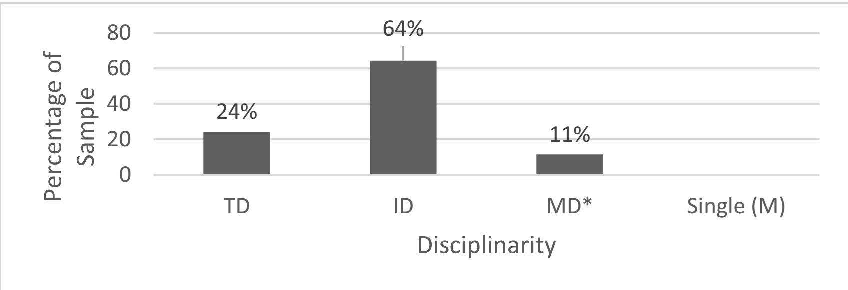

Figure 5. Classification of engineering academic literature by disciplinarity.

[2]The complete results dataset can be accessed at https://researchportal.bath.ac.uk/.

4. Discussion & Conclusions

Since the year 2000 a greater number of engineering journal papers have referenced TD (Figure 4). Although showing an increase in numbers, this does not necessarily mean there has been an increase in the overall percentage of TD papers relative to total publications. To test this, further analysis to normalise the data against the increase in engineering papers overall, is required.

The results of the classification (Figure 5) show that although papers might claim to be TD, when applying the coding agenda based on the work of Jantsch, only 24% met the definition. The majority (64%) would be more accurately defined as ID. Less papers (11%) were classified as multi*- and none as mono. This would suggest that a greater challenge lies in differentiating TD from ID, rather than from MD* or M.

The reasons behind the TD / ID coding differences are not known, but could be both unintentional or intentional. Unintentional rationales might look towards the plurality of disciplinary frameworks. In this regard, the authors may not have conducted research which is TD according to Jantsch, but which might meet alternative definitions. Intentional rationales might look towards the current trend towards TD which may encourage research to be framed as TD in order to meet funder requirements or to appear novel.

When attempting to understand a problem such as this it is useful to be able to triangulate findings against other studies. Comparison of these results to other studies is challenging. First, there have been very few serious attempts to categorise the disciplinary state of research [13] and as far as we are aware, none which have looked to assess whether work claiming to be TD meets that definition. Second, the plurality of definitions means that for the studies which do exist, different approaches may have been used. For example, based on the literature and their own experiences during the empirical analysis, Huutoniemi, Klein [13] create a new disciplinary typology. This is used to assess 266 research project proposals funded by the Academy of Finland. They find ~40% (106 projects) to be ID, which is less than our finding of 64% ID. However, cross-comparison of the two results is challenging as not only do the authors use a different approach for classifying disciplinarity, they use different sampling criteria looking at any research *proposals* from 1997 and 2000. This is in contrast to our dataset which looked at any *TD papers* and returned papers from 1980-2018. That is, our dataset contained papers produced nearly two decades later.

Similarly, recent analysis by Van Noorden [22] finds ~35% of Natural Sciences and Engineering and ~50% of Social Sciences publications to be ID. Again, this employs a different method of analysis in which 35 million papers from the Web of Science are automatically classified.

5. Conclusions

Within this study we seek to understand whether engineering papers claiming to be TD, are actually TD. Our results showed that only around a quarter (~24%) of papers referencing TD within their abstract, meet the definition of TD found in the original classification work of Jantsch. The majority (64%) were classified as ID. These findings highlight that within the academic engineering literature there is still much inconsistency in what might be reported as TD and points to the importance of establishing clearer disciplinary definitions and established rules which differentiate TD from ID.

6. Limitations

Currently, it is not a requirement for the author to state the level of disciplinarity of their work. Within this work we use the appearance of the term within the abstract as a proxy for work claiming to be TD. It is recognised that some papers may not be making this claim. Furthermore, within this study classification of disciplinarity is based on analysis of the abstract. Although it is expected that within an academic paper the abstract would represent fully the research undertaken, this is not always the case. Constraining the sample to journal papers appearing on Scopus (and therefore respected sources), mitigates this risk.

7. Future work

The research within this paper seeks to address whether engineering papers which claim to be TD, are indeed TD. During this work we operationalise the work of Jantsch and use this to create a means to classify disciplinarity. Although adding to the understanding, for a more complete picture future research is required:

1. Investigations of possible overlaps between the TD, ID, and MD literature. Research in this area has commenced. A study conducted within the TREND group has analysed N-grams and Bi-grams taken from the abstracts of 8834 papers to ascertain commonalities or differences between disciplinarities. The results of this study are presented as separate paper [23].
2. Undertake research which allows the results of this work to be triangulated. In this regards, studies should look to apply alternative disciplinarity typologies to the same dataset used within this work, or apply the method used within this study to different academic fields.
3. This work looks to identify whether engineering academic literature claiming to be TD is TD. The alternative question is whether there is work which is not identified as TD, but which meets the definition.

Acknowledgement

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Text Analysis of Disciplinary Research Papers

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Abstract. Research literature terminology illustrates that publications claim to pertain to "disciplinary" approaches and researcher's align themselves to specific, multi-, inter- or trans-disciplinarities. Ambiguity exists in definition and application of disciplinarity, hence there is need to establish a coherent application of disciplinarity. We present results of content analysis of research literature claiming to be inter-, multi-, or transdisciplinary to assist in ascertaining commonalities or differences for those disciplinarities. We analyse the abstracts and keywords of 8834 papers, using n-grams and bi-grams, dating from 1970 until 2018, extracting a list of 76,552 terms for comparison. The top 15 most frequent terms characterise each disciplinarity and Venn diagrams of the top 15 features illustrate differences and overlap. A total of six terms appear common to all approaches in the abstracts, with four shared by multi- and inter-, two between inter- and trans-, and none common to multi- and trans-. The term "social science(s)" appears to be a unique feature in the trans- abstracts and our findings identify common text terms such as the "research" feature, common to all disciplinarities. This supports characterising the nature of transdisciplinarity and its unique differences from other approaches such as inclusion of social science(s).

Keywords. Transdisciplinary, Disciplinarity, Engineering Research, Content Analysis

Introduction

The term "discipline" is defined in most dictionaries as "a branch of knowledge, typically one studied in higher education" [1]; the purpose of science is to advance knowledge within disciplines. Traditionally, a set of core disciplines exists, such as maths, physical sciences or humanities, however many newer disciplines, each with their own bodies of research literature, have emerged since the 1970's. As these disciplines have advanced, new merged disciplines such as systems engineering and education studies [1] have emerged and literature relating to types of "disciplinarities", has grown. These "disciplinarities" are differentiated from single disciplinary work by the use of prefixes such as multi- (MD), inter- (ID) or transdisciplinary (TD) [2] defining the governing principles for how disciplinary knowledge is used within and across disciplines. Hence a "disciplinarity" describes the disciplinary process or system within which academic knowledge overlaps and interacts, relating those specific rules for combining expertise or working amongst established core disciplines to create new knowledge.

As research problems and disciplines increase in complexity and branch into other fields, the projects and teams investigating them are forced to become multifaceted (or

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multidimensional) in terms of their knowledge, skills and experience [3]. Global grand challenges and real-world projects typically involve increasing numbers of core academic disciplines and the focus is on the approaches taken to involve or incorporate disciplines and knowledge, hence the disciplinarity. This is especially true for complex societal projects that involve researchers, industry and society, and are typical in engineering [4], making disciplinarity an important issue in engineering. This is evidenced in reviews of scientific literature where, MD, ID and TD approaches have been populous [5,6] but the interchangeable use of the terms [7] mean their differences remain unclear.

The purpose of this paper is to describe the most frequent text terms used in literature to represent different disciplinarities and to empirically establish the differences and overlaps in terminology that exist. This characterisation and semantic clarity are needed to guide researchers to understand what these approaches, such as TD, should feature to solve societal problems [6,8]. To ascertain whether the research approach requires a specific disciplinarity such as MD, ID or TD, a means to understand their core features is much needed. The use of text analysis is one approach to determine what features are common or unique to a type of disciplinarity. Within this paper we describe the computational linguistics approach we have adopted for analysing the literature claiming to be MD, ID and TD. From this analysis we extract and rank the most frequent text concepts associated with each disciplinary category, identifying the terms unique or common. The results are presented in ranked tables and Venn diagrams, highlighting the unique features of MD, ID and TD approaches in literature.

1. Content Analysis Approach

The approach taken in this paper is to create representative lists of most frequent text terms for each disciplinarity by analysing text contents of academic literature pertaining to specific disciplinarities (MD, ID and TD). Samples of literature have been created using the Scopus database as it is a broad discipline database that is an “Index to journals and conference papers across all subject areas.” [9], and hence gathers text from many different disciplinary approaches. Scopus is a comprehensive, general academic publication database and is considered preferential to Web of Science (the two most extensive academic databases) as it provides 20% more coverage and incorporates a wider range of journals [9]. There are many terms used to describe disciplinary approaches but for simplicity and to minimise cross definitions in our analysis, only the core disciplinary definitions MD, ID and TD have been selected for this analysis. It is noted that multiple definitions of disciplinarity can exist within a single text and hence it was necessary to ensure that each sample of literature created for the sampling pertained only to one disciplinary approach. To ensure the samples were accurately labelled as per the authors own classification of their disciplinarity for MD, ID or TD it was necessary to create a search strategy that labelled literature pertaining to only one approach. This was created by including only literature that labelled its disciplinarity in the abstract, keywords and title. The search criteria text is illustrated below in Figure 1.

Each search was created and literature samples selected as per Figure 1. The abstract text, keywords and title were downloaded as comma-separated value (.csv) files. The underlying assumption is that the abstract, keywords and title would succinctly summarise the content of each paper [10] and hence provide enough differentiating text terms to substantiate the approach [11]. The content was further processed using established Natural Language Processing Techniques. First, the words were all made lowercase and "stopwords"** removed. Second, stemming was applied to remove variants in syntax, such as "disciplinary" and "disciplinarity".

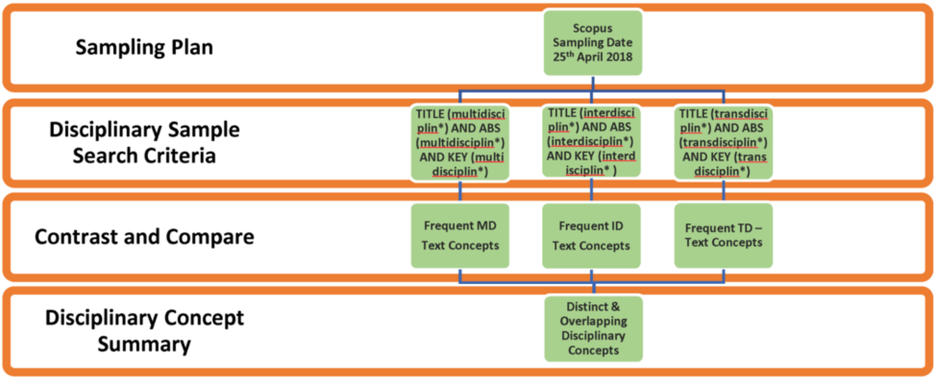

Figure 1. Literature sampling and research approach.

2. Text and Concept Analysis Results

The sampling results of the searches described in Figure 1 are shown in Table 1. If we compare the size of the Scopus literature samples obtained, encouragingly they are proportionally similar to amounts of disciplinary literature found in the work by Bruun [5], where they find that "actively" being TD forms 6% of their funding proposal sample. Their ID research formed 38-46%, however their analysis did not include any growth for the period from 2005 to 2018 and may explain this difference. Their examination of MD was not differentiated from disciplinary and therefore not possible to directly compare.

Table 1. Comparison of sample sizes.

Search String & Prefix	***Trans*disciplin***	***Inter*disciplin***	***Multi*disciplin***
Literature Sample Size	612	4422	3800
Percentage of Sample	6.92%	50.06%	43.02%
Total Keywords	3193	18129	13935
Unique Keyword Tokens	2109	10706	8089
Total Abstract Bi-grams	7238	52519	50702
Unique Abstract Bi-grams	6018	37063	33471

**The Python stop-words library was used (https://pypi.org/project/stop-words/) to remove 127 commonly used words in the English language.

The analysis of keywords and abstracts followed the "bag of words" model. Keywords were split based on the Scopus keyword delimiter ";" and combined to form a list of keywords for each of the three datasets. These were subsequently reduced based on the re-occurrence of terms producing a word occurrence vector for each. Abstracts were split using a regular expression to identify bi-grams and allowing for overlaps. This formed the list of words that were reduced based on the re-occurrence of terms producing a word occurrence vector. An example of such a bi-gram result would be "sustainability science" rather than "science" (n-grams), which alone could be misinterpreted without the context of "sustainability". The resulting frequency ratios for text terms are normalised by literature publication to represent accurately the relevance of each term proportionally over the entire sample.

The distributions in Figure 2 show the keyword and abstract bi-gram occurrence in MD, ID and TD approaches, similar to the "power law" expression of terms used the work by Liu [11]. This simply illustrates that the majority of text concepts in the resulting tables lie within the first 10% of the samples (shown to the left of the dividing line) and hence there are few very significant concepts in the literature. The relevance weighting or proportion of terms occurring to the right of this line means these terms may be of little significance to describe the samples and are unlikely to be represented in our frequent text terms.

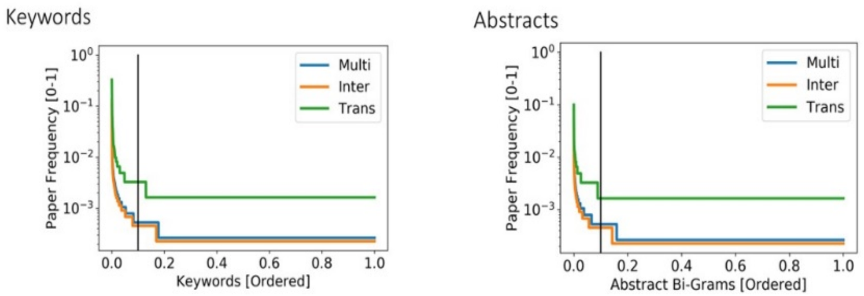

Figure 2. Distribution of text occurrences in MD, ID and TD samples.

The temporal distribution of the sample of literature, shown in Figure 3 below, ranges from 1970 through to 2018 and illustrates that there has been much growth in the utilisation of disciplinary references in the academic literature. Whilst references were first made in the 1970's the growth in MD and ID literature since approximately 1992 far exceeds that of the TD literature.

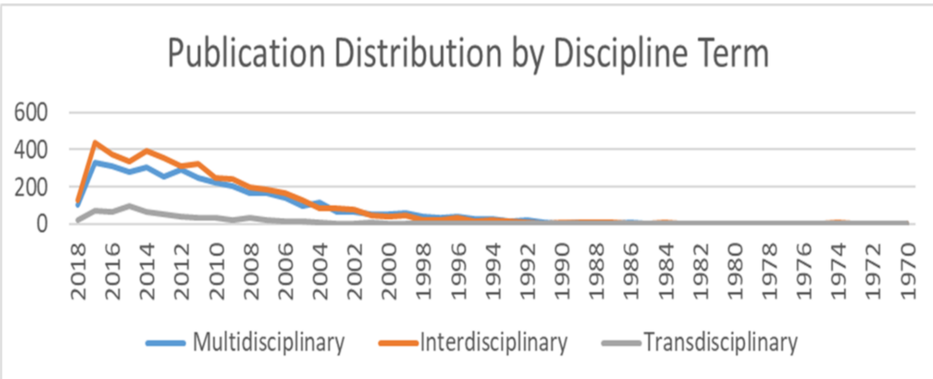

Figure 3. Temporal distribution of literature samples.

2.1 Keywords and Abstracts

The top 10 sample results of the Keyword and Abstracts processing are shown in Table 2 and 3 respectively, with the most frequently occurring terms being listed first. The number of unique tokens processed for the Keywords and Abstracts are listed in Table 1. The representative frequencies are shown in ratio values of the overall samples to enable direct comparison. From these tables it is evident in the TD sample, that there is cross reference to other disciplinarities (use of ID) in the text terms used, substantiating the interchangeable use of terms issue. Due to the extensive size of complete samples, full results are available upon request.

Table 2. Keywords: Top 10 occuring text concepts.

MD	Ratio	ID	Ratio	TD	Ratio
multidisciplinary	0.131	interdisciplinary	0.161	transdisciplinarity	0.388
multidisciplinary design optimization	0.074	interdisciplinarity	0.147	transdisciplinary	0.212
multidisciplinary team	0.059	interdisciplinary research	0.052	transdisciplinary research	0.120
multidisciplinary approach	0.039	collaboration	0.027	interdisciplinarity	0.078
multidisciplinary care	0.032	education	0.025	sustainability	0.055
multidisciplinary treatment	0.032	interdisciplinary collaboration	0.022	interdisciplinary	0.047
multidisciplinary teams	0.023	interdisciplinary education	0.020	complexity	0.039
multidisciplinary design optimization (mdo)	0.017	interdisciplinary approach	0.016	collaboration	0.039
multidisciplinarity	0.016	interdisciplinary team	0.015	sustainable development	0.026
multidisciplinary optimization	0.015	communication	0.012	education	0.022

Table 3. Abstract: Top 10 occuring text concepts.

MD	Ratio	ID	Ratio	TD	Ratio
multidisciplinary design	0.083	interdisciplinary research	0.054	transdisciplinary research	0.099
design optimization	0.057	interdisciplinary approach	0.035	transdisciplinary approach	0.050
multidisciplinary team	0.055	paper describes	0.029	paper presents	0.039
multidisciplinary approach	0.043	paper presents	0.028	case study	0.035
paper presents	0.040	interdisciplinary team	0.028	paper describes	0.021
paper describes	0.029	health care	0.023	transdisciplinary approaches	0.021
results show	0.022	interdisciplinary collaboration	0.020	article describes	0.019
multidisciplinary optimization	0.021	case study	0.017	social sciences	0.016
health care	0.020	article describes	0.016	research project	0.016
multidisciplinary care	0.019	article presents	0.012	paper explores	0.016

2.2 Combined Disciplinary Text Terms

In Table 4 and 5 , we further process the results of our text frequency analysis to reduce the terms to those most representative of MD, ID and TD. These have been calculated using the ratios shown in Tables 2 and 3, with some manual post processing of the samples. The final text frequency lists are the result of manual processing of Tables 2 and 3 results to standardise singular and plural forms, merge synonyms, nouns, gerunds, abbreviations and acronyms [11]. Additional “stopwords” and misleading terms such as “multidisciplinary” or alternative references to the sample designation have also manually been removed from the results to reduce to those concepts most relevant.

Table 4. Most frequent keyword concepts.

MD	%age	ID	%age	TD	%age
design optimisation	9.1	research	6.0	research	23.00
team/teams	8.2	collaboration	4.9	sustainability/sustainable development/sustainability science	9.7
approach	3.9	education	4.5	complexity	3.9
care	3.2	team/teams	2.7	collaboration	2.6
treatment	3.2	communication	2.4	education	2.2
optimisation	2.5	approach	1.6	knowledge integration	2.1
rehabilitation	2.5	higher education	1.0	evaluation	2.1
breast cancer/cancer	2.3	treatment	1.0	approach	1.9
design	1.5	rehabilitation	1.0	participation	1.8
collaborative optimisation	1.4	team work	0.9	climate change	1.8
chronic pain	1.4	curriculum	0.9	methodology	1.6
quality of life	1.0	chronic pain	0.9	epistemology	1.4
education	1.0	care	0.9	health	1.4
clinic	0.9	sustainability	0.9	integration	1.3
communication	0.6	learning	0.8	creativity	1.3

Table 5. Most frequent abstract concepts.

MD	%age	ID	%age	TD	%age
design	8.3	research	5.4	research/research project	11.5
team/teams	7.1	team/teams	4	approach/approaches	7.1
design optimisation	5.7	approach	3.6	case study/ies	4.7
approach	4.4	case study/ies	2.5	social science/s	2.6
optimisation	2.1	health care	2.4	research process	1.5
health care	2.0	collaboration	2	climate change	1.5
care	1.9	work	1	knowledge	1.3
treatment	1.7	mental health	0.9	health care	1.3
design variables	1.4	different disciplines	0.9	action research	1.3
optimisation problem	1.3	team members	0.8	process	1.1
design process	1.3	treatment	0.8	knowledge integration	1.1
case study	1.2	design	0.8	model	1.1
collaborative optimisation	1.2	course	0.8	conceptual framework	1.0
confidence interval	1.2	higher education	0.8	across disciplines	1.0
proposed method	1.2	learning	0.7	different disciplines	1.0
		nature	0.7	sustainable development	1.0

The number of terms that have been merged and removed in the manual post processing mean few concepts remained to describe each sample adequately. Hence a practical approach was taken to include the resulting top most frequent 15 text concepts for each of the disciplinarities for equal comparison. Where there are more terms included in the list, this is as a result of an equal ratio weighting in the 15th term, and all equally frequent concepts are included for completeness. A final list of text terms to describe each of the three disciplinarities is shown in Tables 4 and 5.

There are independent text terms emerging for each of the disciplinarities, however, there is considerable overlap with terms appearing in multiple lists. This is evident in Figures 4, 5, in the Venn diagrams illustrating both independent and overlapping terms. The frequency of terms in Tables 4 and 5 indicates those terms most significant across and within the samples as they are normalized by the number of papers in each sample.

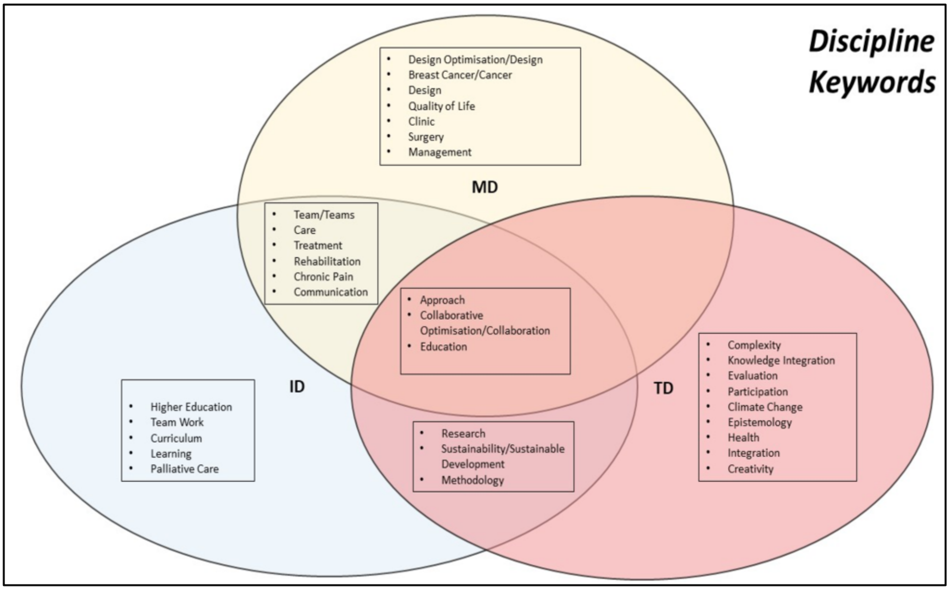

Figure 4. Keywords Overlap.

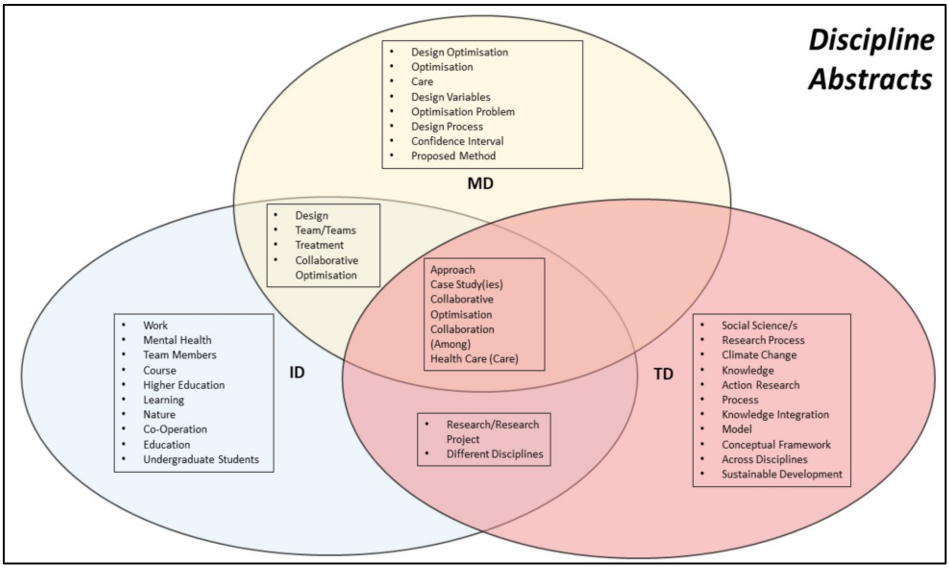

Figure 5. Abstracts overlap.

In Tables 4 and 5 the rate of occurrence of some terms in the "TD" category appear higher than the rate of the same term in the other two categories for example "research" and as the results have been normalized this could indicate significant category features. However, this correlation is observed for academic literature samples and is arguably expected. The authors suggest that this is a limit of the data sample and that further sampling of wider disciplinary text is needed to investigate any hypothesized relationships. Similarly, results suggest the most frequent terms are statistically significant features in respective samples and further work should measure relative significance by comparing frequency distance measures across more or less frequent text terms and disciplinary samples. For example, the relative high frequency of "climate change" in the TD sample, could be compared to its frequency in the ID sample and to other text terms and the natural next stage of this research is to investigate features that appear strongly correlated to samples. Whilst beyond the extent of this work, they could indicate important features and is briefly discussed with a highlight of interesting terms that have potential to form descriptive features for each disciplinarity.

3. Discussion

The growth in the TD literature is minor and Bruun [5] find similarly that only 6% is actively TD. ID in our sample is lower than Bruun [5], which could demonstrate a move towards TD research [6,8]. Alternatively, it could show a pragmatic move by researchers to focus on methods called for by funders in the Grand challenges [4]. It is also possible that the definitions of TD in literature are tightening up and becoming more specific. This variation in definition could skew the temporal distributions of labels that are assigned by researchers and publishers over logitudinal periods of time and hence make interpretation difficult.

It is notable that many of the samples contained multiple references to alternative disciplinarities, such as references in the ID sample to TD or MD. This is demonstrated in Tables 2 and 3, where TD texts make reference to ID. Although not shown in the reduced results, this is also evident in the ID sample, where it also references MD and TD. This evidences the cross over in the use of terms and the potential confusion for researchers about the type of work they may be conducting [7]. It does, however, mean that clarity in definition to use such approaches are much needed for scientists and publishers. The absence of overlap between MD and TD exists in both Figure 4 and 5. This suggests the boundary between them is distinct and hence very well defined in literature. The same absence of overlap in keywords indicates that researchers are clear in their own minds of the difference in these approaches as they are self-selected fields. Hence research should focus upon the definitions of ID and TD approaches where the overlap is prevalent.

The prevalence of '*team/teams'* in MD and ID in Tables 4 and 5, could represent an insular project with rigid bounds focussing on only clearly defined teams. The absence of the term in TD text could characterise the nature of the teams and boundaries being far less distinct and adding to complexity. This in practice may make TD research much less objective and the expected outcomes hard to define.

The prevalence of the term "*research*", whilst perhaps expected in research literature resources, demonstrates a need for higher levels of disciplinarity such as TD, especially in the case of the Grand challenges and societal problems [4]. There is a need to widen the research scope to study those industries, customers and societies that are involved in projects, and in the same way better the research into the role of wider partners and consumers potentially contributing to better outcomes across the entire design and manufacturing chain.

The term *"social science/s"* appears as fourth most important and the term "climate change" as the sixth most frequent in the abstracts of TD literature suggestive of significance and does not appear in the frequent text for ID and MD. If the Venn illustrations were redrawn using the top 40+ and 30+ most frequent terms (respectively) the illustration would still represent these findings. This indicates a high measure of frequency distance referred to in the results, indicating these are necessary features of TD classifications. This fits with descriptions from the OECD [2] of a TD system and is certainly a statistically significant finding for the literature samples we have chosen. These frequency distance measures could be different for alternative samples for example industrial literature and should be further explored.

Additional characteristic text terms appear in the tables for each of the disciplinary categories and appear intrinsic to each. These could represent groups of features that can be used to distinguish between approaches identifying shared attributes. Awareness of context dependent terms such as *"health"* that are also prevalent may then direct the approach suitable for certain types of project.

4. Conclusions

Difficulties in using the correct terminology to describe research approaches is a problem not yet solved. This paper has sought to establish experimentally the text terminology used to describe differing disciplinarities. The disciplinarities analysed included MD, ID and TD, using literature samples from the Scopus database and using an automatic text content and frequency analysis approach. The combined automatic and manual text frequency analysis created lists of text concepts to describe each sample (see Figure 4 and 5). Using this approach, it has been possible to identify sets of text terms that characterise the core features for each of the disciplinarities.

Findings also showed that there are terms used commonly across the disciplinarities, such as *"research"* and context dependent terms such as *"health"*. These terms may be expected in academic literature such as *"research"* or "*health"* and do indicate the focus or context for the projects described in the literature. However, it does indicate that for wider reaching disciplinarities such as TD, we need to explore text from industry or society to fully represent the extent of these approaches.

The features we have identified through our analysis can be utilised by researchers to categorise more accurately their own disciplinary approaches or to identify the most suitable disciplinary approach needed for their research projects. Our findings provide an empirical evidence-based approach to characterising disciplinarities and with further analysis we expect these features to emerge more robustly. This includes extension of the work to create lists of statistically correlated sets of core features and to find text samples that can be analysed to represent the wider communities and their participation in disciplinary approaches. For example, the current push within engineering research for TD approaches is to solve complex problems, using the results from our text frequency analysis it is possible to suggest that to apply a TD approach it would be necessary to involve the social sciences.

The findings presented within this paper present the exploratory results from analysing the academic research literature and the natural progression would to be to increase the literature sampling in a longitudinal study. Hence, in the absence of long study periods, the next practical steps in the process is to extend analysis to full text analysis or to widen the sampling beyond academic literature to industry literature. Over the next 18 months we will be applying a clustering method to identify and define themes within the text concepts and create associations to other literature related to disciplinarity. Through this evolving analysis, the communities understanding and definitions for each type of disciplinarity will be enhanced with the aim of enabling a scientific consensus to be formed on where to apply MD, ID or TD approaches to solve engineering design problems. Once these clear definitions exist we can move on to be able to create appropriate assessments and methods for measuring the benefits of such disciplinary approaches.

Acknowledgement

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TRansdisciplinary ENgineering Design (TREND): Towards a Transdisciplinary Engineering Index

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Abstract. Manufacturing is undergoing rapid change. Whether through the creation of smart materials and products, or utilising data, information and knowledge, the requirement for different ways of working is increasing. To meet future manufacturing needs, design and manufacturing skills and tools must transcend disciplines and industrial sectors. Transdisciplinary Engineering Design (TREND) aims to enable the rapid uptake of emerging technologies across manufacturing sectors and the constitute disciplines. Within this paper, we provide an overview of the TREND research group and their preliminary research towards a Transdisciplinary Engineering Index.

Keywords. Transdisciplinary, Trans-disciplinary, Transdisciplinary Engineering, Transdisciplinary Engineering Research

Introduction

The UK enjoys world leadership in established manufacturing industries such as aerospace, pharmaceuticals, electronic design and photonic technologies. To support continued sustainable growth, UK manufacturing requires cutting-edge research and the development of highly-skilled people [1, 2].

TREND aims to fundamentally change how 21st century products are designed, providing design engineers with a toolkit (models and processes) to support rapid uptake of emerging technologies and enhancement of current technologies across the manufacturing sectors and their constituent disciplines, e.g. Design For Manufacture and Assembly (DFMA) and additive manufacturing in construction. The toolkits will encompass elements such as tools, technologies, processes, and will be data driven and continually evolving.

Such a holistic and evolving approach is necessary to provide the means to rapidly understand and integrate new manufacturing processes, design methods (DfX) and engineering systems and through life support tools into multi-disciplinary engineering teams, in such a way as to transcend disciplines i.e. to be transdisciplinary.

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The ultimate ambition of the TREND team is to design and validate a Transdisciplinary Engineering (TE) Index. The index will provide a practical means through which industry can assess their current TE state, the level of disciplinarity that is required, and then through the toolkit determine the focus of their move towards transdisciplinary engineering.

Within this paper we provide an overview of the TREND research group. First, Section 1 provides an introduction to TREND; their aims and objectives, and theoretical stance with regards to TE. Section 2 details the current research streams within TREND and then describes the progress made towards the creation of a TE Index. Finally, Section 3 outlines the next steps.

1. TREND (TRansdisciplinary ENgineering Design) Research Group

Why focus on Transdisciplinary Engineering? Advances in new technologies such as additive manufacturing (AM), smart materials and digitalisation will result in highly complex systems. Although within the engineering discipline, other approaches have been proposed to deal with complexity (e.g Concurrent Engineering, Collaborative Design Innovation, Design for Sustainability), individually they fail to consider the full range factors which may impact the success of a project. Our hypothesis is that going above and beyond the engineering discipline, TE is best able to overcome this challenge. To this end TREND will create a TE Index and use this to enable TE within industry. Case studies with our industry partners and beyond will be undertaken as a means to test the hypothesis and validate the index.

Fundamental for TREND in its travel towards a TE Index is that the group have a shared mental model for TE. The theoretical stance taken with regard to TE is now presented.

1.1. Transdisciplinary Engineering (TE) - Theoretical Stance

The literature shows there to be a plurality of definitions for transdisciplinarity (TD). TREND adopts the foundational work of Jantsch [3] to inform its theoretical stance for TE. This is due to the fact that Jantsch provides a structure/framework which can be used to assist in the analysis required to apply TE.

Jantsch held that when conducting work in a social context, you need to engage not only the scientific disciplines, but also other dimensions – for example, the social, economic, and political. Using a systems approach, he defined the levels that should be engaged when working towards an objective (Figure 1).

Jantsch's system is coordinated from the top down purposive level, and requires engagement at the empirical, pragmatic and normative levels. The purposive level defines the societal meaning and value which will be delivered by creating a solution to a challenge. The normative level places the challenge in context by considering the social systems e.g. laws, standards and culture. At the bottom of the hierarchy are the empirical and pragmatic levels. The empirical level encapsulates the natural sciences e.g. maths, physics, and psychology. Above this, within the pragmatic level the theories from the natural sciences are merged and trimmed to create the applied disciplines such as engineering.

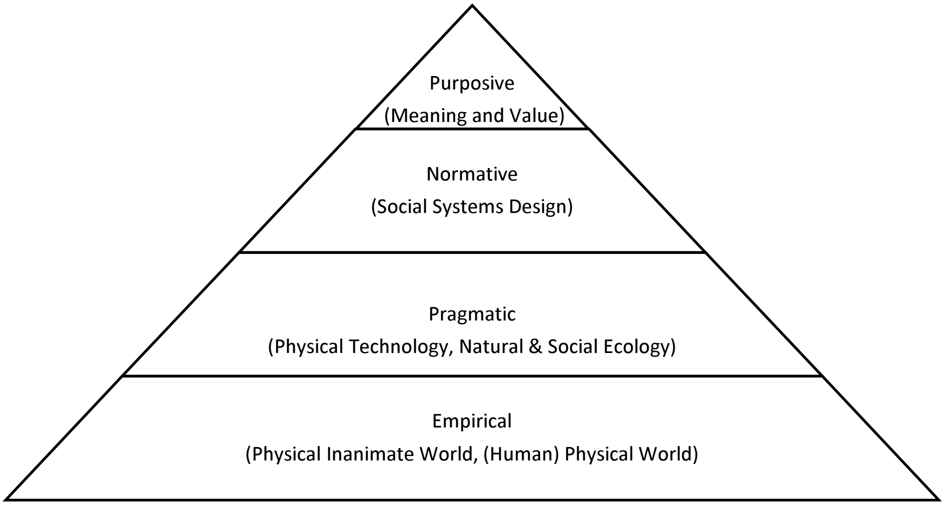

Figure 1. The education/innovation system, viewed as a multi-level multi-goal, hierarchical system. Adapted from Jantsch [3].

Jantsch's works provide TREND with a framework. However, in operationalising the framework, a number of questions arise. One of the key considerations is: at what level should meaning and value be considered? Since its origins in the 1990s TD research has been intrinsically linked to environmental challenges. Within this realm meaning and value is often considered from the perspective of "common good". That is, it is to the public good and of advantage to everyone. However, papers presented within the International Society of Transdisciplinary Engineering Conference have focussed on operational as well as "grand challenge" problems [4] . In this regard the outcomes may not benefit all individuals, but rather a group or subset of society.

When discussing meaning and value within his papers, Jantsch is ambiguous. For example, at one point Jantsch states that the purposive level (the level at which meaning and value is defined), could have a goal of "progress", and then references "progress" from a Christian thought viewpoint which from a western perspective could be economic and technological dynamism. However, elsewhere he describes meaning and value being about a *policy for mankind* – which suggests a grander ambition. The position of TREND is that our research will be independent of specific values. That is, meaning and value will be defined by the context we are working within.

2. TREND Streams

TREND has four work streams, which are coordinated towards creating and evaluating the TE Index (Figure 2).

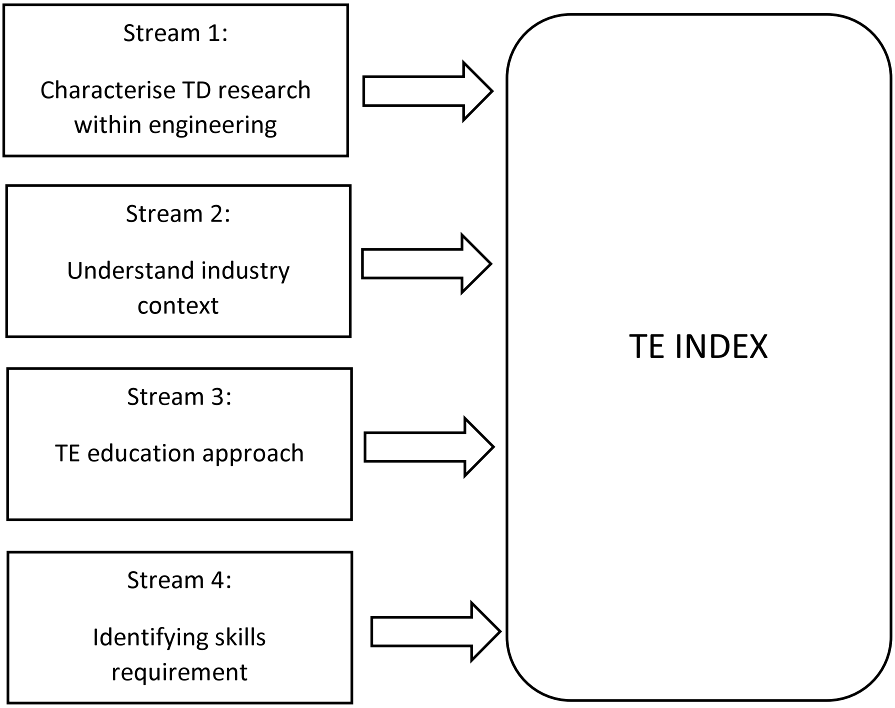

Figure 2. TREND Work Streams

2.1. Stream 1: Characterising TD Research within Engineering

Although there has been an increased discourse around TD research, the assertion was that it had received less attention within engineering [5, 6]. To understand the current state, TREND conducted a study which compared the chronology, comparison of journals, and comparison of text of papers which reference TD within their abstract, to papers which reference TD and fall within the engineering subject area [4].

The research concluded that the referencing of TD within papers is limited both generally, and within engineering specifically. In addition, it identifies that although TD research has historically been biased towards sustainability challenges, within engineering the focus is wider with an increased application towards operational problems e.g. managing the performance of decision support tools within infrastructure organisations [7], the automatic generation of digital twins based on scanning and object recognition [8], a mobile stroke unit for rural Australia [9], efficient design and production of houses [10] and industrial systems modelling [11].

2.2. Stream 2: Understanding Industry Context

The work conducted within Stream 1 provided an understanding of the state of TD within academic engineering literature. It did not provide insights into the awareness, application and use of TD within industry. To address this gap TREND has engaged and is continuing to work with industry through formal research (detailed below) and informal discussions.

Work on a formal research study with the practitioner community is ongoing. This study is being conducted in two stages: Stage 1: semi-structured interviews. Stage 2: questionnaire. Stage 1 is complete. The results of these interviews will be used in conjunction with our findings from the literature review (Stream 1) to inform the design of a questionnaire (Stage 2). The questionnaire enables a greater breadth of industry input facilitating both increased data and international participation.

During Stage 1, the researchers conducted in-depth semi-structured interviews with employees from thirteen engineering businesses. These organisations represented a breadth of sectors and size of organisation. Within the semi-structured interviews five research questions were explored:

Q1. Whether they had heard of the term transdisciplinarity? If so, what did they understand it to mean?

Q2. What levels of disciplinarity they use within their organisations?

Q3. What were the challenges to TD working?

Q4. What were the enablers to TD working?

Q5. What were the inhibitors to TD working?

The research questions were informed by the academic literature and Jantsch's framework. Q1 sought to ascertain whether the term TD was used within industry. Q2, was to determine whether they are working in a TD manner or the level of disciplinarity they are currently working at. This was important as some companies may be working in a TD manner but not referring to it as such. Q3-5 were to determine if working in a TD manner what the challenges were and if not working in a TD manner what the perceived challenges may be.

Early results show that the term TD is not widely used within industry, however evidence of TE approaches are present. Where they are using the term it is often being more narrowly utilised: more akin to inter- than transdisciplinary working. TD working was aspirational for a number of the organisations with a key enabler of TD considered to be effective communication.

2.3 Stream 3: TE Education Approach

To facilitate TD, the emerging literature has called for the expansion of TD education [3, 12-16]. Within Stream 3 TREND looks to create a practical approach for TE education, which can be incorporated into exisiting engineering course designs. The overall aim being to facilitate wider dissemination and engage students from the outset to think wider than a single discipline. The details of the first stage of this research, a pilot with students from the University of Bath's Advanced Automotive Propulsion Systems Centre for Doctoral Training, are presented as a separate paper within this conference [17]. The results, evaluated by way of student feedback, show broad satisfaction with the session. Six of the eight indicated that they were satisfied with the quality of the session (two students were neutral). All students considered that the course material was presented in a clear and understandable way. All students considered that the course was accessible to their level of understanding. Further work to assess the TE education benefits are ongoing.

2.4. Stream 4: Identifying Skills Requirements

Identifying skills requirements to enable TE working and how they may influence the TE Index requires several intermediate considerations. First, how are skills defined? This is a difficult question to answer as skills are often subjectively defined. For instance, LinkedIn allows members to have up to 50 skills, which can either be selected from a database or be entirely user-defined. As researchers we are thus faced with the choice of either defining a set of skills which we will use in the research, or to develop methods to extract skills from data relevant to the system of interest. This research takes the latter approach, where we are developing high-fidelity skills extraction methods. This method includes e.g. creating algorithms to extract and classify concepts from text and then identify which concepts likely belong to a skill, competence, or knowledge class.

This is being done in parallel to understanding the collaboration patterns occurring within and between different organisations. This allows us to analyse the collaborative structures that are driving the work at an organisation, and consequently allows us to understand the communities that are forming, the bottlenecks that may be occurring, and the collaborators most central to the organisation and its various communities.

Applying the skills extraction method to appropriate datasets within our systems of interest allows us to not only consider the organisational affiliation, but also the skills structure within an organisation. Using growth models allows us to extend this to what skills will be more in demand in the future as well as identifying what are the underpinning skills required for working in a TE manner. Finally, as all skills are associated with people, we are able to make evidence-based decisions for the skills requirements for individuals.

3. TREND – Current Findings and Future Steps

The changing landscape of manufacturing make it a designated field for TD. The proposed TE Index will provide industry with a practical approach through which to assess their current level and state of disciplinary working. Then, where desirable, the toolkit will enable their movement towards more effective Transdisciplinary Engineering.

Although, significant steps have been taken towards the TE Index, more research effort is required before the final design of the index can be proposed. A cornerstone of the TE research approach is that it is top-down, with the design of the "solution" informed by the context [7]. Only once the full picture is known can efforts turn to how academic and non-academic insights might be brought together to create an approach which is both rigorous and practical in an industry setting.

To this end, over the coming months we will synthesise findings from the research streams and work with our industry partners and beyond as a way to inform the initial TE Index design. This index will be presented at TE2021 in Bath. The current findings from these streams and future research steps are summarised below:

Although receiving increased academic attention TD remains an emerging, immature field within engineering. The purpose of characterising the literature (Stream 1) was to provide a benchmark of the state of TD within engineering compared to the wider landscape. The study provides insights and highlights that both within engineering and the literature more generally, TD penetration is low. Furthermore, although generally TD has focussed on "grand challenges", within engineering TD has been applied to a broader scope of problems. Although providing some understanding it is recognised that the study presents only one perspective, showing how the term TD is being used within the engineering academic literature. Our future work will explore other perspectives and in doing so add to the richness of the picture. For example, to what extent the academic engineering literature claiming to be TD satisfies the various definitions of TD and whether there is engineering literature which is not identifying itself as TD, but which can be considered to meet the criteria.

The TE Index is intended to be a practitioner-based approach. Key to its uptake within industry is having awareness of the context in which it will operate and incorporating this understanding within the design. From Stream 1 we know that within the academic literature TD is applied across a wide range of challenges. Within Stream 2 interviews we explore where practitioners feel TD might be useful and what are they consider to be the enablers and inhibitors to TD working. Preliminary analysis suggests that although TD working is aspirational with some evidence that indicates it may be being used, TD is not a well recognised term. Although of interest, these findings have limitations as interviews have only been conducted on a small scale. Over the next months we will complete thematic analysis of the interviews and bring this together with insights gained through the other research streams in order to create the industry questionnaire (Stage 2). This questionnaire will enable a wider reach both in terms of sample size and geography.

Recognising that TD is not a well recognised term within industry, research efforts have focussed on creating a practical approach for incorporating TE within higher education engineering courses (Stream 3). A TE session has been conducted and successfully piloted at the University of Bath. Over the next twelve months this session will be delivered to engineering Masters students at the University and later, to PhD candidates within the faculty of engineering at Universidad de los Andes, Colombia. From this activity not only is TE disseminated, it provides scope for additional data gathering. For example, as part of the group discussion element the students are asked to identify enablers and inhibitors for TE. These insights will provide additional data to supplement the questionnaire conducted within Stream 2.

Underpinning the creation of TE education session (Stream 4) is an understanding of the skills which enable TE working. Research to extract the skills sets of engineers is being undertaken. Over the coming months this fundamental work will be built upon in order to define the skills for TE working. This understanding will inform both the TE Index and also to inform a TE Designer Readiness Level, which is the subject of a separate PhD research project.

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An Appraisal and Classification of the Transdisciplinarity of Existing Design Tools

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Abstract. Transdisciplinary (TD) working offers the potential to bring together potentially disparate elements of engineering projects permitting them to concomitantly be addressed on empirical, pragmatic, normative and purposive levels. Whilst the importance and potential benefits of working in this manner are widely accepted, a key inhibitor to the adoption and embedding of TD working in practice is the variety and diversity of design tools employed and their relative levels of ability to support TD working. To explore what can be thought of as the enabling or inhibiting roles of design tools, this paper appraises common design tools and classifies them according to the level of transdisciplinary working that they permit. This is achieved by considering the capturable level of design rationale for each design tool as per Jantsch and contextualising each within the design process. The discussion considers how these findings are reflected in practice and how chains of particular tools could be employed to support TD working across the different phases of the design process. In total 41 tools are appraised with 6 acting as enablers of interdisciplinary working but none identified as truly TD. Most notably, a much greater proportion of TD enabling design tools are available to support the early phases of design. Further work might consider how education can be used to ensure effective use of current design tools and how knowledge transfer can and should be, applied to enable use of TD tool chains in industry.

Keywords. Transdisciplinary Engineering, Design Tools, Design Methods

Introduction

Over the last two decades academic research into Transdisciplinarity (TD) has increased tenfold [1], arguably to realise its potential in increasing the societal value of research [2]. This is achieved by ensuring that the research outcomes generated are in accord with the needs of society [3].

Despite this crucial benefit, TD working faces a number of inherent obstacles related to traditional team structuring and working. These include overcoming professional cultures [4] and cognitive cultural differences [5] that exist within disciplines and challenging cross-discipline collaboration [6].

In the context of engineering, it is considered that TD has received less attention than in other fields including social sciences and medicine [7]. As such implementation

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of Transdisciplinary Engineering (TE) faces an additional obstacle in that TD approaches are not typically considered within engineering projects.

In addressing these obstacles, a key challenge for TD research is identified. It is found that there is a need to train for both collaboration and knowledge sharing with other disciplines whilst also emphasising shared processes and methodologies for generating solutions [8]. In engineering, in both academia and industry, these elements can be partly facilitated by the design tools and methods that are used. Depending on the affordances of these design tools, TD working could thus be enabled or inhibited.

Correspondingly, to identify the extent to which this might be the case, the research presented in this paper seeks to assess the level of disciplinary working afforded by a wide variety of design tools and contextualises them with respect to where they are used in the design process. In doing this, it enables the elucidation of which tools enable or inhibit TD working and subsequent considerations for the implications that these have on TD practice and education.

The paper's contributions are three-fold. First, the paper presents a method of assessing the TD of existing design tools. Second, it provides an appraisal of a wide range of existing design tools and approaches with respect to their ability to enable TD working. Third, building upon this analysis, the paper presents the concept of TD tool chains. In providing these contributions, the paper enables a move towards the explicit incorporation of TD practices in engineering projects where they are, at present, rarely considered.

The remainder of the paper is structured as follows. First, to contextualise the work, an overview of transdisciplinarity, state of the art in TD working, design tools and methods are given. Following this, a method of appraising the level of TD of a design tool is presented. This is then applied to a range of common design tools used in engineering practice. Based upon these results, the discussion considers whether: any of the tools analysed can be considered to be facilitators of transdisciplinary working; the availability of the tools across the design process; whether toolchains can be configured to enable TD working; and, finally the implications of the research findings upon TD education and practice.

1. Background

This background section will explore three key areas in order to situate the remainder of the paper. These are Jantsch's levels of Transdisciplinarity, state of the art in TD working for engineering projects and design tools and methods.

It is beyond the scope of this paper to give an exhaustive definition of TD as a plurality exist (for a more complete exploration please see [9]). What is common within these different definitions is that there is a need to go above and beyond the scientific disciplines to interact or incorporate non-scientific expertise [10]. Of these various TD definitions, Jantsch's work is considered to be foundational where it is defined as permitting a project to work simultaneously on purposive, normative, pragmatic and empirical levels [11]. **Figure 1** demonstrates these four levels with their associated categories of discipline. Within these levels a number of types of disciplinarity exist, ranging from mono- to trans-. These are also defined in **Figure 1**. These definitions of types of disciplinary working as-per Jantsch will be used to classify the various design tools and as such, form the definitions of TD that will be referred to in this paper.

The state of the art for TD working in engineering projects considers a number of relevant areas. These include the development of new TD platforms, measuring levels of TD and identifying where TD concepts are used in projects. Platforms such as GOUVERNe TIDDD have been developed that are considered to be TD, achieving this through the provision of 'interfaces of mediation between policy spheres and sectors of society' [12]. Whilst the development of new platforms is useful, what is more pressing is the assessment of existing tools in order to gain an understanding of the extent to which readily available tools and techniques can enable TE and which of these can be used or connected together to enable TD working.

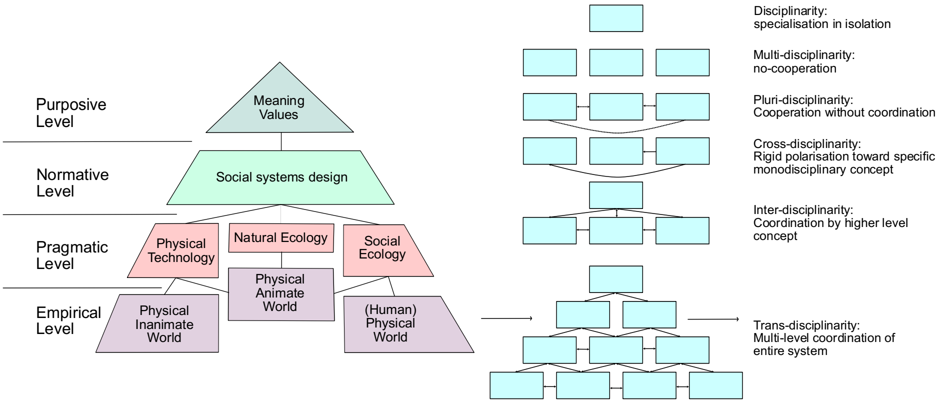

Figure 1. (Left) Jantsch's Transdisciplinarity, (Right) disciplinarity levels (both from [11] and re-illustrated)

Work has looked at developing metrics for assessing levels of TD in projects. These include the development of a quantitative metric to assess the impact of a TE project [13] and a conceptual framework for evaluating TD science [14]. Both of these have looked at project outputs on the whole, rather than enabling tools and methods.

Other work has looked at where transdisciplinary engineering is applied in projects, revealing that TE is used principally at the strategic level and also that effective TE relies upon the relationship between specialisation and generalisation [15]. This again, did not address the affordances of tools within these projects.

This section defines design tools and methods and presents the ways in which they will be contextualised within the design process.

Design tools and methods can be thought of as those that contribute to design thinking and/or the engineering design process. As such, the design process will be considered from these two perspectives. The former to categorise design activities, and the latter to chronologically order phases of design.

The foundations of design thinking (shown in) originate from Herbert Simon's Sciences of the artificial [16]. They comprise of the activities of empathise, define, ideate, prototype and test. They can be considered crucial in the successful execution of TE projects as they enable knowledge transfer between phases and domains of projects. This is highlighted as a recurrent issue in TD literature in the form of knowledge representation and communication, due to the need to communicate complex and dynamic insights that need to be articulated in decision spaces [12].

Pahl and Beitz's prescriptive design process considers the design process in four main stages; clarification of task, conceptual design, embodiment design and detail design [17]. Rather than concerning design activities, they represent phases of design.

The stages of design thinking can be thought to correlate more closely with the first two stages of Pahl & Beitz. In this way we can see a distinction between design and engineering design in that a large part of activities are focussed on the realisation and implementation a solution as opposed to the generation of an acceptable and feasible design.

With respect to the design tools to be appraised, Cambridge University's Institute for Manufacturing's list of Design Management tools and techniques [18] were selected. It was found to be the most exhaustive list of design tools and methods available spanning all stages of design thinking and phases of the engineering design process.

2. Appraisal of support for Transdisciplinarity

Having defined the design tools to appraise, and the design frameworks in which they will be contextualised, this section presents the means by which level of transdisciplinary support enabled by design tools and methods can be appraised.

A qualitative assessment will be made as to which of Jantsch's levels of disciplinarity (as defined in Section 0) a given design tool can contribute towards. This will consider first whether a design method influences (able to change) and/or conveys (passes on) design rationale a given level of disciplinarity. Second, it considers whether this is forced by the method itself or through the choice of the user. The last two factors consider whether we are accounting for TD tools or TD users. A breakdown of the questions asked for each design tool are as follows:

- For each level of Jantsch: (i) is design rationale at this level influenced (i) by this tool? (ii) is design rationale at this level conveyed (C) by this tool? (iii) is working at this level forced by the tool (T) itself or by the capabilities of the user (U)? (iv) Does this design tool force links to be made between the levels defined by Jantsch?
- For each stage of design thinking: Does the use of this tool correspond to this stage of design thinking?
- For each stage of Pahl and Beitz's prescriptive design process: Can this tool be used at this phase of the engineering design process?

In doing this, four elements will be elicited for each design tool:

1. The levels of Jantsch's hierarchy of disciplinarity for which they can they can convey design rationale.
2. Whether explicit links are made between these levels.
3. Is the above centred around the user's capability or is it forced by the tool itself.
4. What elements of the design thinking and the Pahl and Beitz design process respectively can they be used for.

3. Appraising common design tools

The assessment of the various tools is time bound according to the level of familiarity the author has with each. These will be grouped according to three categories: (i) Very

Table 1. Results from analysis of common design tools and methods. Acronyms are defined in Section 3.

	Jantsch's levels of Disciplinarity					Stages of Design Thinking					Pahl and Beitz			
	Purp.	Norm.	Prag.	Emp.	Link?	E	D	I	P	T	T	C	E	D
Market Understanding														
Market segmentation [19]	I C U	I C U	I U	-	-	Y	Y	-	-	-	Y	-	-	-
Purchasing Motivation Matrix	I C U	I C U	I U	-	-	Y	-	-	-	-	Y	-	-	-
Market Structure Illustration	-	C U	-	-	-	Y	-	-	-	-	Y	Y	-	-
Market size and share estimation	-	I U	I U	-	-	Y	-	-	-	-	Y	-	-	-
Competitive analysis [20]	I U	I U	-	-	-	Y	-	-	-	-	Y	-	-	-
User understanding and involvement														
User/customer groups	I U	I U	I U	I U	-	Y	-	-	-	-	Y	Y	-	-
Focus Groups [21]	I C U	I C U	I C U	I C U	-	Y	Y	-	-	-	Y	Y	-	-
Lead user analysis	I U	I U	I U	I C U	-	Y	-	-	-	-	Y	-	-	-
Stakeholder selection	-	I U	I U	-	-	Y	-	-	-	-	Y	-	-	-
User profiling – personas [22]	I C U	I C U	I C U	-	-	Y	-	-	-	-	Y	Y	-	-
Direct observation	-	I U	I U	-	-	Y	-	-	-	-	Y	-	-	-
Delphi Technique	I U	I U	I U	-	-	Y	-	-	-	-	Y	-	-	-
Contextual inquiry	-	I U	I U	-	-	Y	-	-	-	-	Y	-	-	-
Product Definition														
Conjoint analysis [23]	-	-	I C U	-	-	Y	-	-	Y	-	-	Y	Y	-
Kano Model [24]	I C U	I C U	-	-	-	Y	Y	-	-	-	Y	Y	-	-
QFD *[25]*	C T	C T	I C T	I C T	Y	-	Y	-	Y	Y	Y	Y	Y	Y
Image boards	C U	I C U	I C U	-	-	Y	-	-	-	-	Y	-	-	-
Affinity diagrams	C T	I C U	C U	-	Y	Y	-	-	-	-	Y	-	-	-
Product on a page - mission	I C U	I C T	I U	-	Y	-	Y	-	-	-	Y	-	-	-
Product on a page - advert	C U	C U	I C U	-	Y	-	Y	-	-	-	Y	Y	-	-
The "elevator speech"	C U	C U	-	-	-	-	Y	-	-	-	Y	Y	-	-
Concept Design and Prototyping														
Controlled convergence	C U	C U	C U	C U	-	-	-	Y	-	-	-	Y	-	-
Morphological charts	C U	-	I C T	I U	-	-	-	Y	-	-	-	Y	-	-
Osborn's Checklist	I U	-	I C U	U Y	-	-	-	Y	-	-	-	Y	-	-
Weighting and rating	C U	C U	C U	C U	-	-	-	Y	-	-	-	Y	-	-
Concept selection: Dot sticking	-	I U	I U	-	-	-	-	Y	-	-	-	Y	-	-
Four types of testing	I C U	I C U	I C U	I C U	-	Y	Y	Y	Y	Y	Y	Y	Y	Y
Design for production														
Unit Cost analysis [26]	-	I T	C T	C T	-	-	-	Y	-	-	-	Y	Y	-
Booth. & Dew. complexity factor	-	-	I C T	I C T	-	-	-	Y	-	-	-	Y	Y	-
Value engineering / value analysis	C T	C T	I C T	-	Y	-	-	Y	-	-	-	Y	Y	-
Project Generation														
Brainstorming [27]	I C U	I U	I U	I U	-	Y	Y	Y	-	-	Y	Y	-	-
Brain writing / 6-3-5 method [28]	I C U	I U	I U	I U	-	-	-	Y	-	-	-	Y	-	-
Process and project management														
Process on a page	C T	C T	C T	-	-	-	Y	-	-	-	-	-	-	-
Project on a page	-	I T	-	-	-	-	-	-	-	-	Y	Y	Y	Y
Process mapping (brown paper)	-	I C T	-	-	-	-	-	-	-	-	-	-	-	-
Risk assessment	-	C T	-	-	-	-	-	-	-	-	Y	Y	Y	Y
FMEA [29]	C U	C U	-	I C T	Y	-	-	Y	Y	Y	-	Y	Y	Y
Metrics	-	C U	-	-	-	-	-	-	-	-	-	-	-	-
Organisation														
Belbin's team roles	C T	I C T	-	-	-	-	-	-	-	-	-	-	-	-
Who / When map	-	I C T	-	-	-	-	-	-	-	-	-	-	-	-
Project Teams	-	I C T	-	-	-	-	-	-	-	-	-	-	-	-

familiar – 15 minutes will be spent assessing the design tool; (ii) Familiar - 30 mins will be spent assessing the design tool; (iii) Not familiar – 1 hour will be spent assessing the design tool.

The assessment was carried out by the researcher (a post-doctroal research associate) over a period of four weeks, with approximately 30 hours spent in total reviewing and assessing the listed design tools. In total 41 tools were assessed according the aforementioned criteria. The results of this are shown in **Table 1**. Within this table columns 1-4 detail how the tools respond to Jantsch's levels of transdisciplinarity and whether they influence (I) and/or convey (C) meaning at this level and whether this is facilitated by the user (U) or the tool (T). The link column refers to whether a design tool forces links between Jantsch's levels of disciplinarity. Stages of design thinking are abbreviated as Empathise (E), Define (D), Ideate (I), Prototype (P) and Test (T). Phases of Pahl and Beitz are abbreviated as Task clarification (T), Concept design (C), Embodiment design (E) and Detail design (D). Tools marked in red and italics are used in the toolchain proposed in the discussion section. Information regarding tools was sourced from IFM [18] with additions from other references if referenced in **Table 1**.

Notable findings from design tool assessment are as that only 6 design tools make explicit links between levels of Jantsch and that with respect to the levels of Jantsch that a tool can influence or convey, 71 are user-dependent and 28 tool-dependent.

4. Discussion & Further Work

To explore the implications of these results, this discussion section considers the key findings from the analysis carried out. A TE tool chain approach is proposed based on the analysis. Finally recommendations for increasing and facilitating TD working in education and in practice are given.

Two tools were found that are able to convey and influence design rationale at all Jantsch's levels of disciplinarity which are focus groups and four types of testing. However, these are all entirely user dependent in the sense that whilst the tools are able to consider all levels, it is only if the user is able to and chooses to use them in this manner. Also neither of these tools makes explicit links between levels. This can be accounted for by the lack of definition in how these should be carried out. These tools therefore cannot be considered as transdisciplinary. By making explicit links between disciplinary levels, the following tools can be considered enablers of TD working:

- **QFD** – by linking requirements with technical characteristics.
- **Affinity Diagrams** -by forming and grouping requirements from technical characteristics.
- **Product on a page (mission and advert)** – by bringing together the motivation for a project, intended outcomes and product features that enable its realisation.
- **Value engineering / Value analysis –** links cost factors with elements of a design that enable it to deliver its functionality.
- **Failure Modes and Effects Analysis** – links components and their potential mechanisms of failure with the higher-level consequences of this.

Whilst they are unable to perform at all Jantsch's levels of disciplinarity, by linking different levels they can be considered interdisciplinary design tools. They are shown in **Table 2**. It is important to note that whilst levels of disciplinarity could be linked through the use of other tools, in these cases it is user dependent rather than an explicit part of the tool's function. For this reason these other tools were not included here.

These tools can therefore be considered as relative enablers of TD working. These can be seen to be more available in the earlier phases of the engineering design process with 4/6 used in task clarification, 4/6 used in concept design, 3/6 in embodiment design and 2/6 used in detail design. With respect to design thinking, of the tools 1/6, 3/6, 2/6, 2/6 and 2/6 correspond to the activities of empathise, define, ideate, prototype and test respectively.

Table 2. Shortlist of TD enabling tools. Abbreviations are defined in Section 3

	Jantsch's levels of Disciplinarity					Design thinking					Pahl & Beitz			
	Purp	Norm	Prag	Emp	Link	E	D	I	P	T	T	C	E	D
QFD	C T	C T	I C T	I C T	Y	-	Y	-	Y	Y	Y	Y	Y	Y
Affinity diagrams	C T	I C U	C U	-	Y	Y	-	-	-	-	Y	-	-	-
Prod. on a page - mission	I C U	I C T	I U	-	Y	-	Y	-	-	-	Y	-	-	-
Prod. on a page - advert	C U	C U	I C U	-	Y	-	Y	-	-	-	Y	Y	-	-
Value engineering	C T	C T	I C T	-	Y	-	-	Y	-	-	-	Y	Y	-
FMEA	C U	C U	-	I C T	Y	-	-	Y	Y	Y	-	Y	Y	Y

Whilst no design tools were found to individually be TD, tool chains were identified that could enable TE working. In order for a tool chain to be TE applicable, it must be able to both convey and influence design rationale at every level of Jantsch, be motivated by the tool itself, not the use and make explicit links between levels.

Whilst the tool chain must exhibit these characteristics, individual tools would not necessarily have to. The practicalities of the presented tool chain are not considered as this involves knowledge transfer considerations which are beyond the scope of this paper. What the presented tool chain allows is a method of visualising whether TD is permitted throughout the life of the design process. To be considered for the toolchain, tools had to work across different levels and this working had to be enabled by the tool itself rather than the expertise of the user. The tools included are shown in and are as follows:

1. **Product on a page** – to clarify the purpose of the product and how it will achieve this.
2. **Belbin's team roles** – to clarify who is the necessary in undertaking the project and what their roles are.
3. **Process on a page** – to clarify the design process to be followed.
4. **QFD** – to link requirements to technical characteristics.
5. **Value engineering** – compare costs of different manners of delivering elements of a product's function.

   FMEA – Identify potential problems in the product or design process to realise it, covering issues associated with organisation, strategy, product design, production processes and individual components.

Table 3. Shortlist of tools included in a TD tool chain. Abbreviations are defined in Section 3.

	Jantsch's levels of transdisciplinarity					Design thinking					Pahl & Beitz			
	Purp	Norm	Prag	Emp	Link	E	D	I	P	T	T	C	E	D
QFD	C T	C T	I C T	I C T	Y	-	Y	-	Y	Y	Y	Y	Y	Y
Product on a page	C U	C U	I C U	-	Y	-	Y	-	-	-	Y	Y	-	-
Value engineering	C T	C T	I C T	-	Y	-	-	Y	-	-	-	Y	Y	-
FMEA	C U	C U	-	I C T	Y	-	-	Y	Y	Y	-	Y	Y	Y
Belbin's team roles	C T	I C T	-	-	-	-	-	-	-	-	-	-	-	-

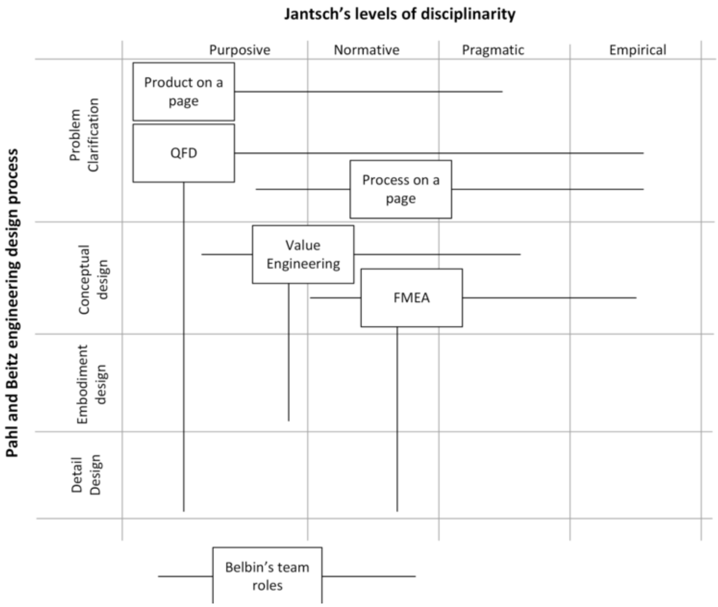

Figure 2. TD toolchain demonstrating how the tools are used with respect to Jantsch's levels and also the Pahl and Beitz design approach

The use of these tools in this order can, in theory, enable connections between all levels of Jantsch throughout the full Pahl and Beitz design process. The notable omission from this is in the earliest phase of the design process with respect to stakeholder engagement and capture of product or process requirements. In the analysis, no means of capturing either of these was found that was enabled by the tool rather than the user. As such none of the tools appraised can be considered to fulfil the empathise stage associated with design thinking.

What is not considered however, is a way of knowing if the breadth of knowledge (with respect to technical disciplines) is covered by these design methods. This comes down to the variety of areas that are covered by TD research. The development of medical implants and hydropower stations are both transdisciplinary, but these will understandably have very different needs.

This variety in TD projects coupled with no clear method of capturing stakeholder requirements creates a chicken and egg scenario. How do you know you are using a correct set of tools for your project given robust capture of stakeholder requirements is difficult? And how do you know you have adequately captured stakeholder requirements if you do not know what you are developing and the process you will use to do it? To address this, an iterative method is necessary to concomitantly generate both of these.

Tools are either found to be open to user interpretation and as such, their effective and potentially TD use is entirely dependent upon the capabilities of the user. On the other hand, some tools are found to be inter-disciplinary if operated in accordance with their prescribed methods of use. This inevitably requires training to enable this. Correspondingly, two key implications can be presented regarding education and practice respectively.

First, in order to prepare students more generally for TE working, they need to be taught a wide range of TE principles in order to apply these in design tasks. This could be done directly through lecturing as is generally done or through the implementation of more practical TD design courses where students across faculties are brought together to solve real problems (such as the course *vacile creativo en San Basilio de Palenque* run in la Universidad Jorge Tadeo Lozano in Bogota [30]).

Second, in design practice, adequate training needs to be provided in order to ensure design tools that could enable ID or TD working are used in this way. This could be done through the use of existing training programs or through the use of external facilitators who are well versed with using the tools.

Immediate further work centres on the development and delivery of workshops that can be used to teach TD principles such that they can be directly applied to their research projects. This is in response to the identified need to educate students to enable them to effectively use a number of existing design tools in a TD manner.

A secondary stream of further work is to use the initial findings from the study and apply them to industry. The aim of this is explore the way in which tools and tool chains are used in industrial processes to identify whether these can be considered TD.

Third, exploration into knowledge transfer techniques in order to enable the transfer of design rationale across design tools. The proposed TD tool chain assumes that this can be carried out without loss of design rationale. Investigation needs to be carried out to confirm that this is the case.

5. Conclusion

This paper appraises and classifies the level of transdisciplinary working enabled by a range of existing design tools and methods. This is carried out in order to elucidate the extent to which design tools can be key enablers of knowledge sharing and collaboration across disciplines.

Of the design tools assessed it is found that none can enable TD working, but six can enable interdisciplinary working. Given the lack of TD tools, the concept of TD toolchains is presented as means of achieving TD capability throughout the design process by combining existing tools. An example of such a tool chain was presented and consisted of product on a page, Belbin’s team roles, process on a page, QFD, Value engineering and FMEA.

The implications of these findings with respect to education and practice are that working with tools in TD manners requires people who can think in TD ways. As such, ensuring people are familiar with these concepts is essential in enabling effective working. Further work looks at the implementation of workshops to introduce TD concepts, and exploring techniques to ensure successful knowledge transfer across design tools.

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Transdisciplinary Approach to Hyper-Transparency

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Abstract. Over the last decade, transparency schemes have started to undergo a radical transformation. This transformation is driven by advancements in cloud computing, cryptography and automated measurement technology, which have made it possible to develop shared information management systems (SIMS). These SIMS form the backbone of the latest, state-of-the-art in the transparency space: hyper-transparency schemes. These new transparency schemes and associated SIMS offer companies, both small and large, the opportunity to redesign their supply chains and to establish more direct relationships with their second- and third-tier trading partners, as well as with the consumer. However, the companies also face various challenges in implementing and operating such hyper-transparency schemes. There are legitimate concerns about privacy, ownership and access to data and, related to this, who controls the SIMS. The present paper discusses the ongoing development of a SIMS. The objective of this SIMS is to: (1), help empower smallholders in agri-food supply chains to establish more direct connections with the consumer; and (2), help empower consumers to get more direct insight into the manner in which their food stuff is being produced. The paper presents the design of the SIMS and discusses its transdisciplinary development processes.

Keywords. Transdisciplinary, transparency, hyper-transparency, shared information management systems, supply chain redesign

Introduction

Over the last decade, transparency schemes have started to undergo a radical transformation. This transformation is driven by advancements in digital technologies, which have made it possible to develop shared information management systems (SIMS). The development of a SIMS is a challenging task. As with all new technology it is important not only to develop a robust system that is useful and usable, but also a system for which the impact on the user community and the society are well anticipated. In the literature, examples can be found of systems which had a large (often unanticipated or unexpected) impact on the procedures and working culture of a company or supply chain, (see e.g., [1]). Always, an information system alters the way people work, while, conversely, people also alter the way in which the system was supposed to be used.

The development of a SIMS requires collaboration between several different disciplines, preferably both from technical and social-science disciplines and from both practice and academia. Engineers alone are not sufficient. People with knowledge of the

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context in which the system needs to function, in this case supply chains with improved transparency and hyper-transparency (see section 1), as well as people from the social sciences who can apply methods to identify user interface needs. The development of such a system, therefore, requires a transdisciplinary approach (see e.g., [2, 3]). With such an approach the context of the system under development as well as of the business, in this case the supply chain, is well taken into account. The context can be wide, not only including the use context, but also the political, financial, cultural, etc., context.

In this paper an example of the development of a SIMS is presented. This SIMS is targeted at New Zealand agri-food supply chains and is intended to help companies create hyper-transparency schemes. Such schemes enable companies to give the consumers, as well as their supply chain partners, direct and real-time insight into the origin and production circumstances of the inputs or end-product that they are buying.

The goal of the system is twofold. Firstly, to help New Zealand companies restore consumer confidence at home, where farmers and food companies are under threat to lose their social license to produce because of environmental and animal welfare concerns. Giving consumers direct insight into the farm their products come from, and especially into the efforts the farmers undertake to take care of their animals and to limit environmental waste, could bring consumers and farmers closer together. Second, the objective is to help ensure the continued confidence of overseas consumers in the safety of New Zealand food products. Especially in a post-COVID-19 world, companies and supply chains that can demonstrate in real-time that they are going the "extra-mile" to ensure food safety, are likely to gain a significant premium.

The outline of the paper is as follows. In Section 1 we contrast traditional transparency schemes with hyper-transparency schemes. In Section 2 we describe how the SIMS functions. In section 3 we describe its development process. Section 4 concludes the paper.

1. From transparency to hyper-transparency

Up until the late 2000s, transparency schemes encouraged the consumer to rely on the monitoring activities of retailers and certifying institutions to guarantee a product's origin and quality (e.g., [4, 5]). This required little involvement of the consumer, but also meant little real transparency: the consumer was asked to "trust" a label, stamped onto the product (see [6]). However, over the last couple of years, new transparency schemes have emerged to facilitate and encourage consumers to become more directly "involved" in the food production process. This has enabled consumers to actively monitor product attributes or production process characteristics by themselves.

Transparency schemes in the 2000s can best be characterized as link-to-link information systems, with an uni-directional focus, that were grounded in fragmented IT architectures (see Figure 1). Link-to-link in this context means that information almost exclusively flowed from one stage in the supply chain to the next, and rarely skipped a stage in the process (e. g., one-step forward or backward; see [7, 8]). Uni-directional means that the efforts at transparency were mainly oriented towards providing more information to downstream agents about the activities of the upstream agents, rather than also providing the upstream agents with information about downstream activities (see [9]). The IT architectures supporting the transparency schemes were fragmented, because most agents stored information in their own private databases (e.g., about production processes activities, product attributes, measurement results) that had limited or no direct connectivity to the databases used by agents elsewhere in the supply chain (an issue not just limited to the agri-food sector; see [10]). Combined with the link-to-link nature of the information flows, this meant that the information that was generated upstream in the supply chain was relatively slow to reach the downstream agents and not always reliable.

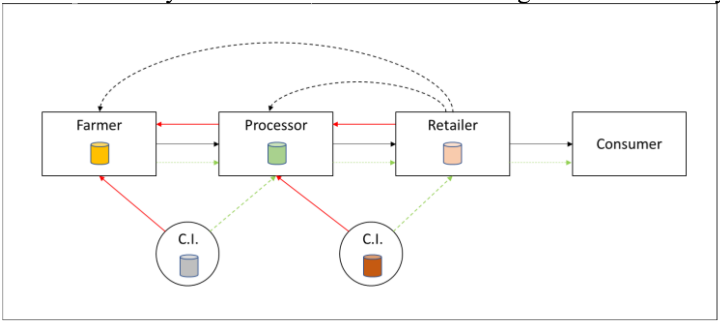

Figure 1. Typical transparency scheme (2000s).

Uninterrupted black lines: flow of products; interrupted black lines: flow of standards; uninterrupted red lines: monitoring activity; interrupted green lines: quality signalling; CI: certifying institution; different color-coded cylinders represent proprietary databases.

Advances in digital technologies over the last decade, especially in the area of cloud computing and cryptography, have started to transform the nature of transparency schemes. These advancements have made it possible to develop shared information management systems (SIMS), which form the backbone of these new transparency schemes (e.g., see [11]). We refer to these new types of transparency schemes here as "hyper-transparent", to clearly differentiate them from older schemes (see Table 1).

These SIMSs function by ensuring that: (1), the individual databases of the parties participating in the transparency scheme run on the same IT architecture; (2), these databases are connected; (3), changes cannot be made to individual database as long as these changes are not approved by (some of) the other agents; (4), once changes are approved, they appear in other databases as well (e.g., [12, 13]). De facto, this means that each agent holds a copy of the same database, and therefore has – potentially at least – access to the same data. This makes almost real-time flows of validated data possible; data that can be bi-directional in nature and link-to-system rather than link-to-link.

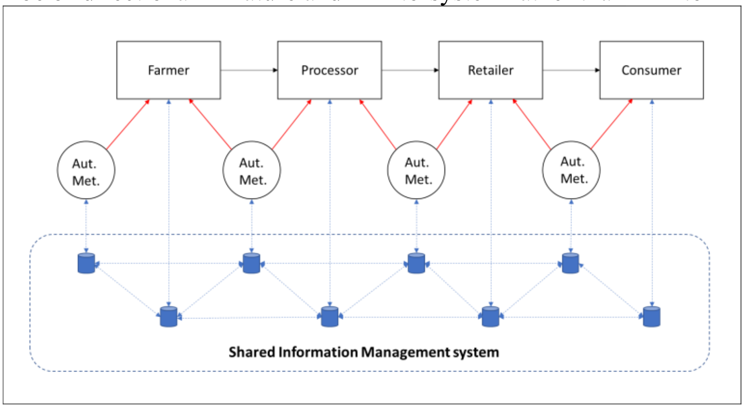

Figure 2. Example of hyper transparency scheme.

Uninterrupted black lines: product flows; uninterrupted red lines: monitoring activity; interrupted blue lines: information flows; the blue cylinders represent copies of the same, shared database; Auto Met.: Automated metering.

Arguably the most revolutionary aspect of these SIMSs is that they, together with improvements in measurement technology, can help to transform some credence attributes of food products into search attributes. Consumers could get, at least as long as the (major) parties participating in the transparency scheme agree to this, direct access and data points about what is happening at the processing or farm level. They would no longer be forced to delegate monitoring duties to other agents, but could, if they wish so, also do it themselves. Thus, for example, a consumer could potentially get direct insight into how animals are treated in different processing plants, when he/she is comparing meat products in the supermarket (e.g., via a live camera feed, accessed via an QR-code on the food packages). Animal welfare, in this scenario, would no longer be a credence attribute, but would become a search attribute (at least to a certain degree).

Furthermore, bidirectional flows of information, where the upstream agents get more insight into what happens downstream in the supply chain, could also change the way in which the companies in the supply chain deal with each other. Amongst others, they could help to reduce and mitigate some disputes in the supply chain. For example, if an upstream agent can track in real-time how long it takes for its outputs to move through the supply chain and see for itself immediately when there is a delay somewhere, it could make it more receptive to a delay in payment. Additionally, these bidirectional flows of information can also strongly enhance the ability of upstream agents to get direct and unmediated insight into consumer interests and behaviour. To return to the example given above, a processing plant could get insight into the frequency by which consumers scan the QR-code on the food packaging, etc.

Of course, hyper-transparency schemes have potential drawbacks as well. There are legitimate concerns about privacy, ownership and access to data and, related to this, who controls the SIMS. In many cases, the implementation of SIMSs is driven by the larger companies in the supply chain, such as retailers (e.g., [14, 15, 16]). These large companies de facto control who gains access to what part of the database. Therefore, while the other agents in the supply chain could easily have access to the same data as the retailer, usually they have access to only part of the database. In such cases, the potential of SIMSs for supporting bidirectional and "stage-skipping" information flows remain largely unfulfilled. Furthermore, the suppliers of SIMSs, who usually are large IT firms (see [17]), may become key "middlemen" in the agri-food industry [18]. These firms may make it difficult for the users of a SIMS to switch to another SIMS, thereby locking them into a relationship they cannot easily get out of.

Table 1. A comparison between transparency and hyper transparency schemes.

	Traditional Transparency Scheme	*Hyper-Transparency Scheme (ideal type)*
Focus of transparency efforts	Mainly **uni-directional;** providing downstream agents (e.g., retailers, consumers) more insight into the operations of upstream agents (e.g., farmers).	**Bi-directional**: providing downstream agents (e.g., consumers) with direct insight into the operations of upstream agents (e.g., farmers), and the latter also with direct insight into the needs and behaviour of the former.
Information flows	Mostly **node-to-node**; preceding, accompanying or following the flow of inputs/outputs throughout the supply chain.	**Node-to-system**: once a link in the supply chain releases information, it becomes available to all the other links at the same time.
IT architecture	**Fragmented architecture**, characterized by **isolated silos of data.**	**Integrated architecture**, underpinned by a **shared information management system.**

Speed and accuracy of information exchanges	Comparatively **slow**, **error-prone** information exchanges as a result of node-to-node communication that is “supported” by a fragment IT architecture.	Almost **instantaneous exchange** of **validated information**, that is much **less error prone** due to: an integrated IT architecture, multiple automated measurement technologies to triangulate the validity of measurements, use of sophisticated encryption technology.
Support of consumer monitoring efforts	The scheme encourages and asks consumers to **rely on the monitoring activities of third-parties** (e.g., certifying institutions, regulators) and food sellers.	The scheme facilitates and **encourages active and direct monitoring by consumers** of product attributes and production process characteristics.
Impact on consumer – seller/producer information asymmetries	The underlying **information asymmetries are not addressed**, but are shifted to the ‘relationship’ between the consumer and monitoring agencies. Consumers are asked to have confidence in the monitoring activities of these agencies.	By facilitating direct monitoring by the consumer, the scheme can **transform** (some) **credence attributes** (e.g., animal welfare) of food products **into search attributes** (e.g., by giving the consumers the opportunity to verify animal welfare by themselves).

2. The Envisioned system

The SIMS that we are developing is being designed specifically for smallholder-led supply chains. A SIMS can support smallholders by drastically lowering the time and costs of keeping track of the origin of food products along the supply chain. This could enable more smallholders to market their products as differentiated goods to consumers and it could also enable consumers to link the products they are buying to a specific farmer or farm-systems. With this in mind, the objective in designing the system was twofold: (a), to help farmers in establishing more direct relationships with their consumers; (b) to give consumers direct insight into how their food-products are made.

The system is made-up of five sub-components: (1), a farm- module; (2), a post-farm gate module; (3), a consumer module; (4), a communication module; and (5), an infrastructure module supporting the other four elements.

The farm-level module (see Figure 3) refers to the sub-system through which data is collected at the farm. Mostly, this will be done via sensors and IoT enabled devices, that automatically collect farm-level data (e.g., environmental data, data about animal behaviour, etc.) and uploading it to the cloud. For example, we are planning to use GNSS positioning sensors on cows, enabled with LoRA wireless technology, to track and record the activities of the animals and benchmark this data against indicators of animal health. We also intend to use WiFi-enabled cameras with motion detectors that can track the animals around the farm to provide a visual indication of how the animals are doing. Also, farmers will also be able to manually upload farm data to the cloud (e.g., information about their water usage).

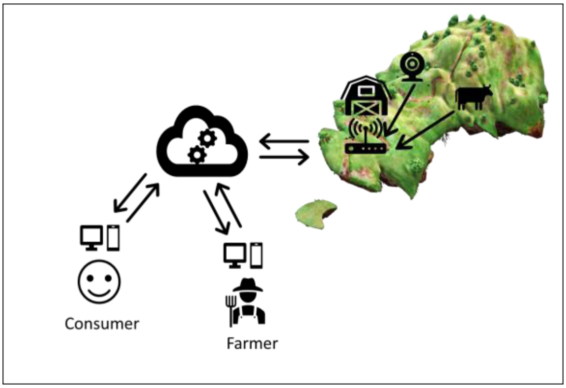

Figure 3. Overview of farm-level module.

In the post-farm gate module, we aim to deal with the problem of gathering and integrating verifiable information into the SIMS about agricultural "inputs" or "products" after they have left the farm gate. In many agri-food supply chains this can be challenging. For example, it is often difficult to keep track of products at the processing stage of the supply chain [19]. At this stage, "inputs" from different types of farm often get mixed and it can be prohibitively costly for the processor to keep product flows from different types of farm separated. Technological advances, however, give companies in the supply chain a couple of options around this problem. Firstly, technologies are being developed in some agricultural supply chains that allow farmers to undertake processing activities by themselves (e.g., such as on-farm dairy processing). Subsequently, the farmer can sell its products directly to the consumer. Secondly, novel measurement and sensor technology have been developed that when linked to a SIMS, help to drastically reduce the time and costs of: (a), keeping track of the origin of food products (e.g., DNA based-tracing of premium meat products); or (b), providing verifiable information about product attributes that can link measurements at the processing stage of the supply chain back to the type of farming system under which the products have been produced. Box 1 gives an example of the latter. This is a methodology that AgResearch is developing for the dairy industry, and our SIMS will be linked to it.

Milk composition and structure is significantly affected by the type of farming system under which the milk is produced (e.g., type of feed), by cow breed and by seasonal factors. AgResearch is investigating a cost-effective way to assess milk attributes based on these factors, both at the farm and at the processor. The ability to collect information about milk attributes throughout the supply chain will support a more transparent way to provide verifiable information to the consumer. In the method under development at AgResearch, 'molecular signatures' are traced that give an indication of the various earlier mentioned "value-added" attributes of milk. This molecular signature can be evaluated at the farm gate and the factory gate through the help of a special sensor. A mathematical model helps the company to relate the measurements taken to the value-added attributes of the milk.

Box 1: Verifiable milk attributes

Through the consumer module, buyers of food products can get insight into how their products are made. Here, the main concerns are: (1), how to make the process of getting access as easy as possible for consumers; (2), how can we stimulate them to actually engage with the platform. To deal with the first challenge, we will be using QR-codes, whereby consumers scan a code on the packaging of the food product with their phone and then visit the farmer's website (see Figure 4 for a prototype). To deal with the second challenge, we have analysed existing websites in the food-transparency space and are undertaking a consumer survey. Our preliminary analysis suggests that gains can be made in the following areas vis-à-vis existing approaches: "personalizing" information (e.g., by showing information about individual animals), using more audio-visual information (e.g., through live video-feeds of the farm), by presenting such information in an engaging fashion (e.g., we intend to track animals around the farm through cameras with motion-detection sensors), and by presenting "numerical" data in a "visual" manner.

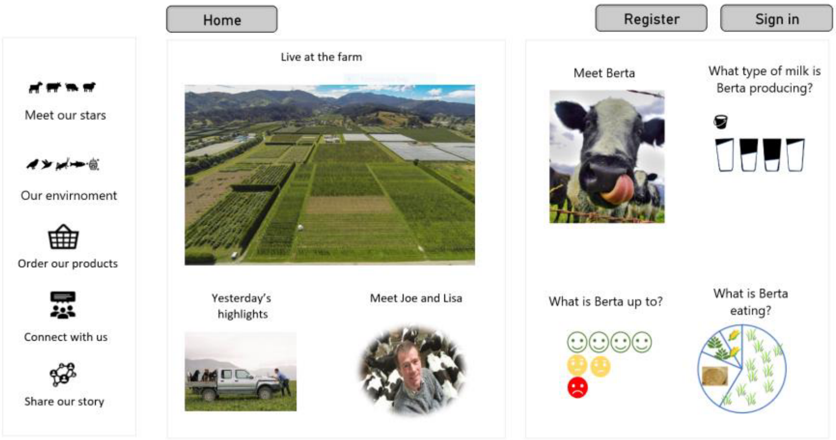

Figure 4. Overview of consumer module.

As shown in Figure 5, the infrastructure module is a cloud-based online platform. Data from the farms and other components of the supply chain are directly and continuously collected via IoT devices and transferred to the data warehouse or data lake managed in the shared system in the cloud. There are three components to this platform. First, the data management system is designed using the schematic proposed in Figure 2. Second, an automated data processing algorithm is implemented to check the quality of data and convert data into desired formats. Data governance, security protocols and proper access control for all actors in the supply chain are implemented here. Third, a data visualization and reporting system is under development.

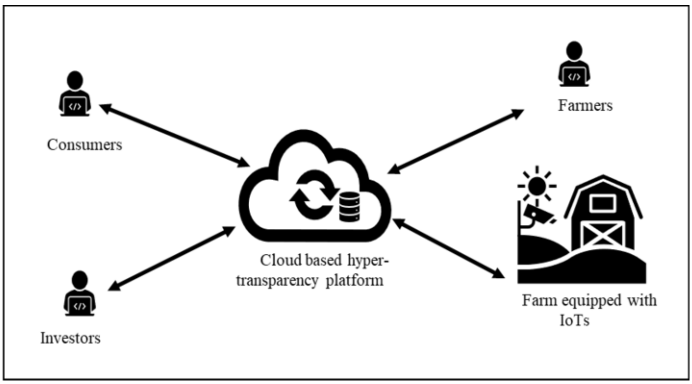

Figure 5. Infrastructure schematic and high-level software architecture.

We envision a communication module where consumers can ask questions to the farmers in real-time about the farm activities. This will allow both parties to not only engage but to clarify potential miscommunications. Farmers are generally busy people and it is hard for them to spare time to communicate with consumers. Realizing this, we propose an Artificial intelligence-based (AI) control system as shown in Figure 6.

An AI control system is equipped with text-to-voice, voice-to-text and Natural Language Processing technologies. Consumers can ask question in both voice and as written text; this will be received by the AI control system. This system will process the content in real-time to check for any abusive behaviour. Questions will be delivered to the famers as voice, which they can listen to via a headset and can answer by voice or text. Subsequently, the AI control system transfers the answer back to the consumer.

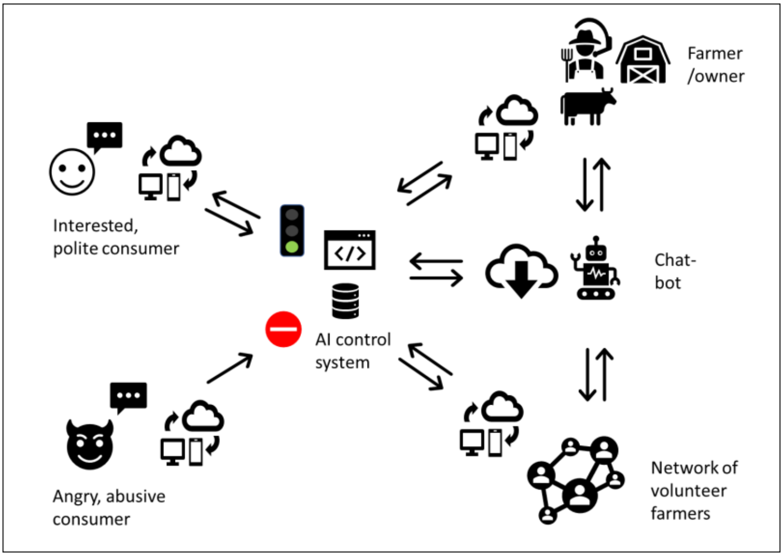

Figure 6. Overview of communication module.

3. Transdisciplinary Development Process

The problem of designing a SIMS is a genuine transdisciplinary challenge, requiring expertise in areas such as data science, robotics, supply chain management, engineering, sensor technology, and economics. With that in mind, the team developing the SIMS was selected based on both the depth and breadth of their knowledge. The core team consists of three people, all of which have a T-shaped skills set, with depth in expertise in at least one of the above-mentioned areas, together with a broad set of interests in other areas. The SIMS-project forms part of a larger program, "NZBIDA"[2], which is dedicated to harnessing the power of digitalization to transform the New Zealand agri-food sector. In the program, about 70 people from a wide range of disciplines participate. Expertise from that pool of people is consulted by the core "SIMS-team" as when required.

[2] New Zealand Bioeconomy in the Digital Age.

The core team is directly responsible for development of four out of the five modules of the SIMS. The exception is the “post-farm gate” module, where the methods for gathering verifiable information about product attributes at the processor stage of the supply chain are developed by another team within the NZBIDA program (the “food authentication” team). One member of the food authentication team functions as a liaison between the two teams and in this way helps to promote collaboration.

As in any transdisciplinary project, there have been challenges. Team-members have had to educate themselves in certain areas and have had to “develop” common concepts and language through which they could efficiently communicate with each other. Also, while there was an abundance of specialized, talented people within the NZBIDA program, comparatively fewer of them also had the T-shaped skills that make transdisciplinary collaboration function more smoothly. This made communication within the wider program sometimes challenging.

Transdisciplinary collaboration requires both the ability and willingness of people to learn new skills and to broaden their horizon. This takes time and much commitment. In that sense, transdisciplinary collaboration is less like some switch that can be turned on and off (depending on the nature of the problem), but more like muscle that needs to be developed through years of cultivation. The effort it takes to be able to contribute to a transdisciplinary project cannot be taken for granted, or this leads to suboptimal results.

4. Discussion and further work

The use of traditional transparency schemes, with their reliance on indirect and uni-directional information flows is unlikely to increase consumer trust in producers and food sellers. Consumers mostly have a transactional relationship with producers and food sellers that is unlikely to change in a meaningful way through the adoption of such schemes. However, hyper-transparency schemes have the potential to change the nature of that relationship to a degree, by facilitating more direct interaction between producers and consumers. In this way, they could bring producers and consumers closer together.

In the present paper we have presented the design of a SIMS to support smallholders in the agri-food sector to implement a hyper-transparency scheme and we have discussed its transdisciplinary development process. Both the design and development process of a SIMS need to factor in not only consumers potential disinterest in the possibilities hyper-transparency schemes bring (by presenting information to the consumer in an engaging fashion), but also how to deal with the potential unwillingness of the larger players in the supply chain to support and participate in these schemes. Especially, companies operating at the processing stage of supply chains traditionally have been unwilling to incur additional costs in separating product flows and of sharing sensitive information with their suppliers. A couple of methods were discussed that could help smallholders to reduce or bypass this problem: (1), technologies that enable farmers to undertake some processing activities already at the farm-level); and (2), the use of novel sensor technology that is linked to the SIMS and that can help to dramatically reduce the time and costs of keeping track of the origin of food products.

Hyper-transparency schemes and associated SIMS could become another tool for lead-companies to use for the purpose of further exerting control over their supply chains. However, they could also become a tool that empowers more smallholders to develop and set-up their own supply chains, through which they can market their own, products.

These two futures are not mutually exclusives. To help ensure that SIMS will serve both types of purposes, we are developing the system described here.

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Transdisciplinary Engineering Education

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Towards a Practical Approach for TE Education: A Pilot Study at the University of Bath

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Abstract. Recent decades have seen increased interest in transdisciplinary (TD) research. To deliver on the promise of TD working there has been a call for the expansion of TD education in emerging literature. The challenge with proposed approaches is that they are often difficult to implement requiring significantly changed courses structures, and the coordination of teams of academic and industry experts to deliver. This creates a barrier to the main-streaming of TD education. Our research aims to create a practical approach for Transdisciplinary Engineering (TE) education which can be easily incorporated within existing course designs and in doing so facilitate wider disseminated. This paper presents the design and pilot of a TE session with MRes students from the University of Bath's, Centre of Doctoral Training in Advanced Automotive Propulsion Systems. The session is evaluated by way of student feedback. The results show broad satisfaction with the session. Six of the eight indicated that they were satisfied with the quality of the session (two students were neutral). All students considered that the course material was presented in a clear and understandable way. All students considered that the course was accessible to their level of understanding. Future work will see the session delivered within additional engineering MSc courses at Bath and internationally with informal agreements in place with Universities in Colombia, Korea and Poland.

Keywords. Transdisciplinary Education, Transdisciplinary Engineering Education, Engineering Education, Transdisciplinary Research, Transdisciplinary Engineering Research, Transdisciplinary Engineering, Transdisciplinary Engineering Design

Introduction

Smart factories and industry 4.0 result in complex systems where jobs tasks are augmented by both humans and automation [1]. Transdisciplinary (TD) approaches advocate purposive research which aims to address complex, real world challenges by the collaboration and integration of knowledge which goes above and beyond the academic disciplines [2-4]. As such, there is an expectation that engineering will be a designated field for TD research.

To deliver TD, there has been a call for the expansion of TD education [2, 5-9], and there is an emerging literature presenting potential approaches such as new TD courses and project based learning (PBL) activities. The challenge with these approaches is that

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they are often difficult to implement, requiring considerable effort to plan and execute [10-12]. This acts as a barrier to the main-streaming of TD education.

Within this paper a transdisciplinary engineering (TE) education session which can be delivered by one member of the engineering faculty, within a two hour period is described. The case study presents a pilot of the session with MRes students from the University of Bath's, Centre of Doctoral Training in Advanced Automotive Propulsion Systems.

The paper is structured as follows: First, a brief background to TD and the TD education literature (1). Following, the proposed TE session design is described (2). The pilot study with the Advanced Automotive Propulsion Systems (AAPS), Centre for Doctoral Training (CDT) is introduced (3) and student evaluation of the session presented (4). Finally, conclusions are formulated (5) and future work identified (6).

1. Transdisciplinarity

The origins of TD can be traced back to an educational conference held in Paris in 1970s [13]. Within this conference Jantsch presented a paper which described a hierarchical education/innovation system [2]. This conceptualised TD as a purposive system aimed at achieving societal meaning and value. In the conceptualisation the system is divided into four levels. The highest level is the Purposive level: societal meaning and value. Below this are the Normative (social-systems), Pragmatic (applied sciences), and Empirical (natural sciences) levels. To achieve TD all four levels of the system must be engaged, with coordination coming from the purposive level down.

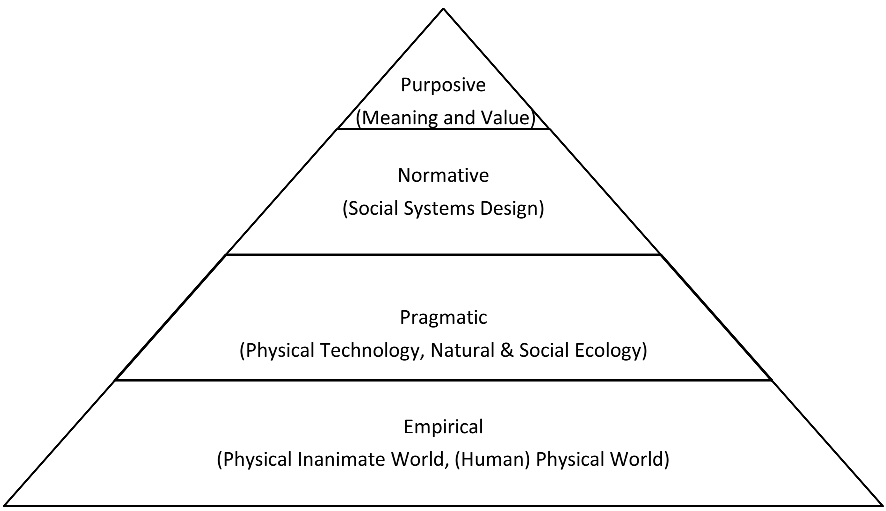

Figure 1. Adapted version of Jantsch's education/innovation system, viewed as a multi-level multi-goal, hierarchical system [14].

Despite these early endeavours, TD remained practically uncited until the 1990s and the rise in environmental awareness [13, 15]. In response to a requirement for new systems of working to address this complex problem TD re-emerges, albeit using a plurality of definitions, and papers referencing TD increase from seven in 1990 to in excess of 500 by 2018.

Within this growing body of work there has been a call for TD education, both generally and within engineering specifically [2, 5-9]. To deliver TD education the original work of Jantsch [2] calls for the restructuring of universities. Aligning with the hierarchical system presented in Figure 1, the institution would be reorganised into three types of units: system design laboratories, function orientated departments, and discipline orientated departments. These units create interdisciplinary coordination of the purposive/normative, normative/pragmatic, and pragmatic/empirical levels of the education/innovation system (Figure 2). As the students progress through their education (i.e. undergraduate, Masters, PhD) they advance up through the units.

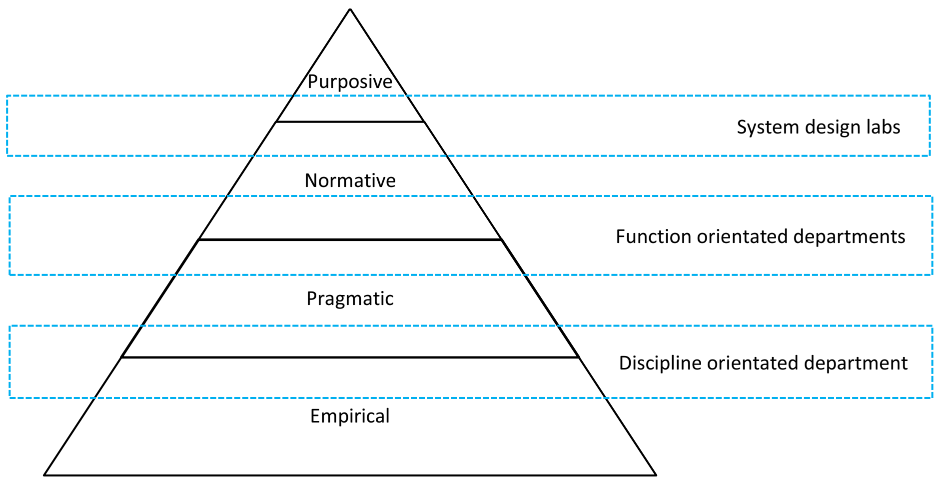

Figure 2. Transdisciplinary university structure. Adapted from Jantsch [2].

The education system proposed by Jantsch requires a significant shift from the traditional UK university set-up. Students would increasingly move towards self-education causing the "university professor, characteristic of the university today, to virtually disappear" [2]. To date, there is a lack of evidence to support that any University has implemented this approach. Rather, the tendency has been less revolutionary with TD education incorporated into existing university structures either through new courses e.g. Ertas [10], the addition of new modules to existing course content e.g. Kellam, Walther [11], or by stand-alone project based learning (PBL) challenges [16].

For Universities, deciding on which strategy to take and then designing new TD content is only one of the challenges faced. By its nature, the content of any TD education programme will be broad. To deliver this content will necessitate the engagement of staff from across multiple faculties and increased involvement from practitioners. This challenge is highlighted by Ertas [10] who called upon industry experts and academics from universities around the world to deliver a TD Master's course offer by Texas Tech University. This calls for lecturers who are open and able to work in a team comprising of academic, practitioner and client experts [17].

Our research aims to overcome these challenges by creating the structure for a practical approach for Transdisciplinary Engineering (TE) education. Within this paper we present a pilot of this session with MRes students from the University of Bath's, Centre of Doctoral Training in Advanced Automotive Propulsion Systems.

2. TE Session Design

A two hour session was constructed to be delivered in four sections (develop motivation; remember/understand; apply; analyse/evaluate), by one member of the engineering faculty (Figure 3).

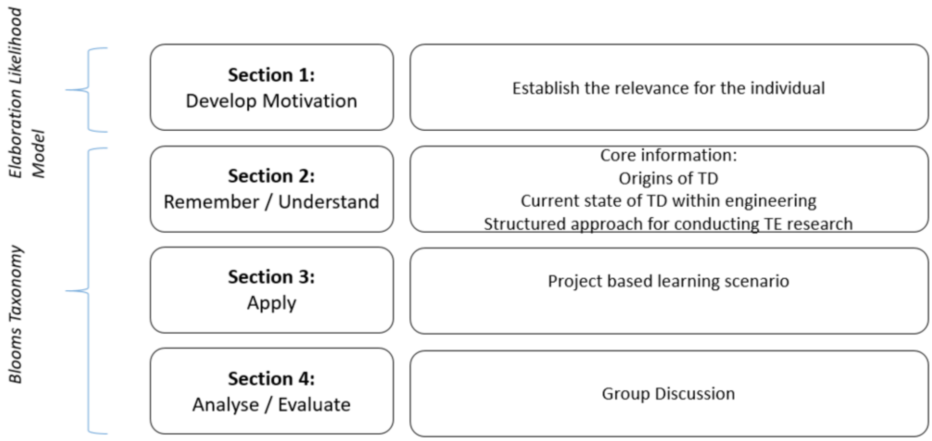

Figure 3. Transdisciplinary Engineering session structure.

The structure of the session was informed by two theories: The Elaboration Likelihood Model [18, 19] and Blooms Taxonomy [20]. The Elaboration Likelihood Model asserts that when a recipient is subjected to information which is intended to persuade them, they will adopt one of two strategies either following a central, or peripheral route. The central route is followed when the recipient engages and scrutinises the information they are presented with. The decision they reach (either supporting or opposing) is based on the strength of that information. However, if the recipient is unmotivated, or cognitively unable to process the information, their decision making will follow the peripheral route. In this case their decision will depend more on exterior cues such as the credibility of the source of the message.

Linked to The Elaboration Likelihood Model *Section 1* aims to "motivate" the students to engage with the information by detailing how the session is relevant to them i.e. how it links to course learning outcomes, or how the learning will be measured within summative assessments.

Bloom's Taxonomy is commonly used as a means through which to provide a shared language when designing educational courses [21, 22]. Aligning to Blooms Taxonomy, *Sections 2 – 4* progress the students through increasing higher levels of learning.

Section 2 is focused on remembering and understanding. Wognum et al. [23] identify not all project based learning will result in an acceptable solution and there should be an emphasis on the learning of shared processes and methodologies. Within this section a presentation is given which provides the students with core information: the origins of TD, the current state of TD within engineering [14], and a structured approach for conducting TE research [24]. Providing a "core" of information reflects the approach used by Ertas [10] in the design of his engineering Masters course.

Section 3 provides the students with the opportunity for application via Project Based Learning (PBL), a commonly used approach when teaching TD [23]. Although there are many advantages to this approach, in practice it is often challenging, taking considerable effort to plan and implement [23]. Our research aimed to create a practical approach for teaching TE. Therefore, the PBL approach was truncated with students asked to design the approach to be used within a project, but not to conduct the project.

A key challenge is selecting an appropriate project [23]. The project chosen here was based on a recent call by the UKRI Engineering and Physical Sciences Research Council (EPSRC). The call had an overall goal of supporting manufacturing research which contributes towards future growth in the UK economy. One of the three themes for which projects could be submitted was Zero Loss Systems (ZLS). The call stated that it was "supporting interdisciplinary research teams to push collaboration and fusion of the research approaches towards a transdisciplinary approach" [25]. Therefore, it provided a "real-world" scenario which had the potential to be addressed in a TE manner.

Although PBL initiatives are often undertaken in groups, we wished to remove the possibility that an individual may dominate the group. To capture the detail of the project a form was created. Based on the work of Jantsch [2] it aimed to elicit information which could be used to classify the level of disciplinarity of the project design. The three questions are:

1. When researching ZLS, what is the overarching *purpose* of your research?
2. When researching ZLS, which disciplines would you include in your team?
3. Other than the disciplines you identify in question 2, would you look to involve anyone else in the project? If so, who?

The students were then asked to classify the disciplinarity of their project using a decision tree. This decision tree, operationalises the work of Jantsch [2], and provides a simple yet robust method for identifying TD research.

Within *Section 4,* the students are guided through a group discussion in which they are encouraged to analyse/evaluate TE. The specific areas they were asked to reflect on are:

1. The level of disciplinarity of the research projects designed within Section 3.
2. The three questions from the project design form used within Section 3.
3. When a TE approach would be useful / not useful?
4. The enablers / barriers to TE?

3. Pilot Study: The Advanced Automotive Propulsion Systems (AAPS) Centre for Doctoral Training

Funded by the UK'S Engineering and Physical Sciences Research Council (EPSRC), The Advanced Automotive Propulsion Systems (AAPS), Centre for Doctoral Training [26] aims to educate the next generation of leaders in the automotive sector. Over the five years from 2019 it will support 86 PhD research projects. These projects are TE in nature; they will be conducted in collaboration with industry partners and look to address the challenges of the automotive sector in its transition towards a more sustainable future. The TE session was developed in response to a requirement of the Centre directors, and was piloted with their student cohort in November 2019.

The AAPS cohort follow a 1 + 3 year course structure. During the first (MRes) year students develop core personal, technical and research skills. The following three years focus on progressing their PhD research projects. The TE session was delivered as part of the MRes unit entitled "Propulsion System Evaluation". This semester long unit sees the students work in groups to firstly analyse the performance of a current propulsion system, and then to identify opportunities for innovation. The defined aims of the unit are:

1. Introduce students to a real automotive propulsion system through practical, data driven analysis of its performance and context
2. Work in a transdisciplinary team to harness the skills and knowledge brought by each individual.
3. Apply structured innovation processes to identify opportunities for future propulsion systems.

Eight of the cohort of nine students took part in the session which lasted two hours. Sections 1-3 were undertaken within the first hour, with the group discussion taking place in the second. Section 4 presents the evaluation of the pilot study.

4. Evaluation – Student Feedback

Evaluation of the session was conducted by way of student feedback. It aimed to capture the student satisfaction with the course rather than assess its performance against learning objectives. The reason for using student feedback as the means of evaluation was two-fold: 1. The University of Bath aspires to deliver excellent education. Within the UK, student satisfaction is a key indicator for University rankings. 2. At the time of conducting the pilot, the data through which to assess performance against learning objectives were not available. Within this unit "Transdisciplinary considerations" are one of a number of unit learning outcomes which are assessed through coursework (a Technical Brief) which students submit later in the academic year.

4.1. Results

In obtaining feedback the students were invited to anonymously complete the standard University of Bath feedback form. The form encompassed four areas: What they felt about the session (Table 1); the session's requirements for background understanding; what worked well; what could be improved; and any additional comments.

Table 1. Summary of TE session student feedback.

How do you feel about this statement?	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
I can see how this session contributes to the overall programme of study	-	1	2	4	1
The learning outcomes for the session were clear throughout	-	2	2	2	2
The material in the course was presented in a clear and understandable way	-	-	-	3	5
The session was accessible for my level of understanding	-	-	-	1	7
Overall, I am satisfied with the quality of the session.	-	-	2	4	2

The student feedback (Table 1) demonstrates a broad satisfaction with the session. Six of the eight indicated that they were satisfied with the quality of the session (two students were neutral). All students considered that the course material was presented in a clear and understandable way. All students considered that the course was accessible to their level of understanding. Receiving a less positive response was how the session fitted within the overall programme and around the clarity of learning outcomes.

Although Section 1 (Develop Motivation), of the session aimed to inform the students of how the TE session met the learning outcomes of the unit, they appear to remain unclear on how the session fed into the overall programme with three of the eight giving a negative or neutral response. This is perhaps a consequence of the session being incorporated within a pre-existing course without the opportunity of amending the description of the course programme. Similarly, learning outcomes were set at a unit level prior to the decision to incorporate a TE session, as such they were high level and not directly aligned to the session content.

When asked to comment of the background knowledge required for the session, six of the eight considered it to be of the right level, whilst two considered it to be too little. In designing the session a conscious decision had been made not to require or assume any background knowledge of the subject. This decision was made for two main reasons: 1. The student's had not been allocated any free study time for research into TE. 2. TE is an emerging area and the seminal literature is yet to become apparent. This would make it difficult for students to navigate independently.

When asked to consider what worked well, the students identified the topic as "interesting" and helping towards "understanding and considering wider impacts on problems". The session was considered to have a " good balance of presenting and discussing". The presentation was considered to provide a "nice overall context" being of "a good length", and enabling them to learn "a lot in a small period of time".

Improvements include more time allocated to explaining the differences between the various disciplinarily levels: "delve into the specifics of TD, MD, ID and varying levels of this after the session", and "provide more scope for deeper discussion". The majority of the feedback related to the resources used in Section 3. These resources, which are based on the work of Jantsch, were considered by some to be confusing. Their comments included "Make question 1 more specific, too many ways to respond" and "Clarity between questions 2 & 3. Seems initially like the same question asked twice."

5. Conclusions

This research conducts a pilot study of a practical approach for TE education undertaken with MRes students from the University of Bath's, Centre of Doctoral Training in Advanced Automotive Propulsion Systems. Evaluation, conducted by way of student feedback, was broadly positive with all of the eight participants considering the course material to be clear and accessible, and seven of the eight considering that it was effective in helping them learn. Future iterations of the session will look to emphasise how the TE fits in to the overall programme of study and expand the time allocated to explaining the differences between disciplinarity levels.

6. Future Work

The development of the TE session, presented within this paper was the response to a need expressed by educational leaders. In meeting this requirement theoretical discussions around the benefits and drawbacks of a Transdisciplinary Engineering education were not considered. Going forward and in testing the generalisability of the approach questions of this nature must be addressed.

Plans have been made to deliver the session to ~80 University of Bath, Engineering Business Management and Business Innovation students and informal agreements are in place to run the session in Universities in Colombia, Korea and Poland. The scope of these future studies will be extended to incorporate these wider research questions. The results of the pilot and the subsequent studies will be synthesised and presented as a journal paper.

Acknowledgements

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Analyzing How University Is Preparing Engineering Students for Industry 4.0

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Abstract: Industry 4.0 is causing a lot of changes related to the way people work, bringing a demand for a new worker profile, mainly for engineers, that need to have not only technical skills but also methodological, social and personal skills. So, there is a need to study and identify how the university prepares engineering students for Industry 4.0 jobs. To achieve this objective a literature review was made, twenty-nine skills of Industry 4.0 jobs were identified, and eight active learning methodologies were selected like paths that universities can use to develop skills for the Industry 4.0. To analyze how a university can use active learning methodologies to develop Industry 4.0 skills in engineering students, a questionnaire was applied in four engineering classes of the University of Brasilia, where the professors answered about the active learning methodology used and what skills were developed in the students, and the students answer the questionnaire with what skills they developed. A correlation analysis was applied to detect the different points of view between professors and students. Then, a decision tree was used to identify what skills were most developed by the active learning methodology used by the professor. The results show that are some divergences between the two points of view, and the questionnaire needs to be adaptable to measure with more reliability the skills that the professor wants to develop in each engineering class.

Keywords: transdisciplinary systems; engineering education; active learning; Industry 4.0.

Introduction

Information security, internet of things, augmented reality, big data, autonomous robots, simulations, additive manufacturing, 3D printing, integrated systems and cloud computing, are examples of technologies that brings up a new industrial scenario and are used in an integrated way to solve problems and generate flexibility so that companies can meet customers' needs [1].

This scenario distinguishes the Fourth Industrial Revolution, represented by Industry 4.0 and characterized by digitalization, high level of technological innovation, real-time information, flexibility and connectivity which, like previous industrial revolutions, has a transformative impact on society, reaching the economy, business models and, consequently, the guidelines of the work environment and the professional profile [2].

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The implementation of the Industry 4.0 scenario is strongly related to collaboration between people who are able to develop new knowledge, concepts, tools and techniques shared by researches from different families of disciplines (social, science, natural science, humanities and engineering), working in a collaborative process to generate knowledge and implement solutions to unstructured problems [3].

This involvement of professionals from different disciplines, with different ways to work and think about ill-defined and complex problems relevant to Society is characterized by transdisciplinary systems, that combine both technical and social disciplines to implemented new technologies, process, practices and knowledge [4].

In this scenario, engineering institutions are restructuring their curricula and teaching models, moving from a purely technical scope to one that considers problem-solving, projects, critical thinking development among other approaches that integrate different forms of teaching and non-traditional engineering knowledge, such as business, finance, management, politics, social studies, and others, in order to develop skills and competencies that form professionals capable of acting in different situations and contexts [5].

Transdisciplinary systems in engineering requires the involvement of people with open mind to other disciplines [4]. Engineering education should incorporate courses whose curriculum prepare students with the knowledge and skills needed to understand and collaborate with people from other disciplines, in other words, the need of not only hard skills but also soft skills [6].

Some courses have been designed to achieve this goal especially those that use active learning methodologies like flipped classroom, problem-based learning (PBL), cooperative learning, peer-led team learning (PLTL), collaborative learning, game-based learning, inquiry-based learning, blended classroom. These are some examples of methodologies founded in literature that aim to implement transdisciplinary in engineering institutions.

Many challenges exist to implement a transdisciplinary approach in a training process, manly in engineering courses. In the traditional curricula was rarely the opportunity to leave the purely technical scope and have contact with real problems, extracting its essence and applying the respective analyzes that lead to decision making and generating solutions, engineering education should be more inclusive, also addressing the development of social, personal and methodological skills [6].

One of these challenges found in literature are how to measure and verify that the transdisciplinary approach implemented by active learning is preparing engineering professionals with Industry 4.0 skills?

This article aims to analyze if the application of an active learning methodology is efficient to collaborate with a transdisciplinary engineering approach to train professionals for Industry 4.0. To achieve this goal first was researched about the set of skills that needed to be developed in an industry 4.0 engineering professional. Secondly a research about active leaning method was made and, based on literature, the skills developed by each method was presented. Then a case study was developed in University of Brasilia (UnB) to compare the information of literature review with a practical situation, considering the point of view from the professor and undergraduates. The tools used to analyze and compare the different viewpoints were correlation analysis and decision tree.

1. Industry 4.0 and the need of a new engineering profile

The Fourth Industrial Revolution brings many changes in the business, in the way people think, the speed of changes and others facts that requires not only a different way to manage a business but also impact in different activities and functions to perform the work [7]. By this scenario is possible to notice that its need to develop new skills to survive the new Industrial era, mainly for the engineers [1].

The engineer must be able to combine technical, social, methodologic, and personal knowledge to work the Industry 4.0. Maffioli and Augusti [8] denote that only the aggregation of pure science knowledge, that includes all knowledge assumed by traditionally technical areas of engineering, like mechanical, mechatronics, robotics, and others are no longer enough to for future professionals.

Lemâitre [9] denote that industries demand skills related to innovation capacity and performance, that can vary from static to dynamic state. Companies that have a static state are characterized by a low level of innovation and long-life circle products, for example, tend to demand professionals with solid technical knowledge. On the other hand, companies with a dynamic state are characterized by high levels of competition, short life circle products and are constantly testing a new process, products, and clients. In this case, the uncertainty is a strong factor in all process, so, the company needs professionals who master technical knowledge and can combine this with different areas to understand and create new solutions to solve ill-defined and socially relevant problems.

Bughin, Manyika and Woetzel [10] declare that professionals will need to developed skills related to sensorial perception, cognitive abilities, problem-solving, planning and optimize activities. They also will need to be creative, own emotional intelligence and know-how to articulate and coordinate teams from different knowledge areas.

To train an Industry 4.0 engineer is necessary to synchronize cognitive, technical, methodological, and social skills development in the learning process. Such combination can impact in the integration of several learning ways content from different knowledge areas and help undergraduates to develop the ability to apply them in different situations and contexts, as well as to continue learning [11].

For future professionals is necessary interpersonal skills development, the engineer must be able to work in teams, consider different perspectives, understand and respect different opinions, and to recognize the experience of professionals from different areas. Consequently, it's necessary to communicate and present new ideas and results, understandable by professionals from other areas[10].

Hecklau *et al.* [12] introduce a set of future professional skills that were clustered into four main categories: methodological, technical, social, and personal. Methodological competencies are related to the knowledge of methods and tools to solve problems, conflicts, make analysis, researches, and to be creative. Technical competencies are related to technical knowledge and experience. Social competencies are related to the ability of teamwork besides understanding and collaborate with different knowledge and viewpoints. Personal competencies are related to the ability to be flexible, tolerant and able to constantly learn. Each skill is presented on Table 1.

Industry 4.0 brings challenges to training new professionals and consequently, the educational institutions and universities need to prepare professionals with the set of skills and competencies of the future industry. The way universities are structuring themselves to this scenario is covered in the next section.

Table 1. Set of future professional skills as proposed by [12].

Methodological	Technical	Personal	Social
Problem solving	Media skills	Flexibility	Leadership skills
Entrepreneurial thinking	State-of-the-art knowledge	Motivation to learn	Team work skills
Creativity	Technical abilities	Complacency	Intercultural skills
Analytical skills	Understand new processes	Sustainable mindset	Ability to commit and cooperate
Research skills	Programming skills	Tolerance	Communication skills
Efficiency in problem solving	Understanding information security	Ability to work under pressure	Ability to transfer knowledge
Decision-making	State of the art knowledge	Flexibility	Master more than one language
			Networking skills

2. How universities are preparing themselves to provide professionals for Industry 4.0

In response to changes in the market as well as the way people think and demand products and services, universities and institutions of education need to review the training process for new professionals. They need to allow undergraduates to apply knowledge to real, ill-defined and society-relevant problems, providing a transdisciplinary approach that engages and enables students to develop the technological knowledge, practical experiences, perspectives, and strategies drawn from a diverse range areas [13].

The transdisciplinary education approach is a way to create opportunities in the curriculum for undergraduates to experience and practice solutions to realistic problems, not simply academic knowledge. This is a student-centered method that involves dynamics classroom approaches with the objectives for students to achieve deeper knowledge through active exploration of real-world challenge and problems[4].

The transdisciplinary approach has seven key features that can be connected to engineering domain as follow [4]:

1. Problem oriented: ill-defined, society-relevant problems are dealt with in a transdisciplinary approach.
2. Involvement from academia and practice: to solve ill-defined, society-relevant complex problems both academic and non-academic stakeholders need to be involved.
3. Both research and practice need to benefit from a transdisciplinary process.
4. Research goals need to be defined by technical (transdisciplinary or inter-multidisciplinary) and social science goals (like business management, human resources, or team composition and culture).
5. Practice goals need to be defined, by different functional goals, like technical, as well as human resources and management goals.
6. Project goals need to be defined, which may shift in the course of the project, because of the dynamic nature of project and unexpected situations that may emerge.
7. Measures need to be defined for the various outcomes of the project.

To implement transdisciplinary education, institutions and universities can use active learning methodologies. Characterized by the student-centered approach, the active learning aims to involve the student in a dynamic process of knowledge construction based on theoretical and practical experiences of real-world situations [3]. Also consider situations to solve working problems with multidisciplinary teams, to promote the collaboration between teams from different disciplines with different viewpoints follow [4].

When the topic active methodologies is researched the main results appointed in the literature are the following methods: Flipped Classroom, is about the dissemination of content outside the classroom, in digital format [14][15][16]; Problem-based learning (PBL), is the application of the content to solve a real problem [17][18][19][20]; Cooperative learning, is the application of strategies that promote cooperation between students to solve a problem [19][18][21]; Peer-led team learning (PLTL), is about solving problems collaboratively, with the help of peers/mentors [22][23]; Game-based learning that brings a proposal of a scenario in which the application of games with certain contents, environments and challenges for solving problems [24][11][25]; Inquiry-based learning, provides students with opportunities to improve their understanding of content and practices covered during teaching [26][27]; Blended classroom is learning within the classroom, complemented with activities and virtual content, which can be accessed outside of class hours [28][29].

Each one is indicated in the literature to provide the learning process by experiences and consequently, develop skills and competencies that probably cannot be achieved by a non-centered-student method and compose the set of Industry 4.0 skills [30]. To analyze those methods in practice and find out if the application of active methodology results on the development of future skills, a case study was applied in some engineering classes of the University of Brasilia (UnB). The applied methodology is presented below.

3. Methodology

The case was implemented by a survey forms, structured based on two main points of the literature review: i) the set of twenty-seven skills introduced by Hecklau *et al.* [12]; ii) the inclusion of two more skills in this set, that were present in literature review that compose the important skills to Industry 4.0: a) critical thinking, characterized by an intentional judgment process that results in interpretation, analysis, evaluation and inference [31]; b) creativity, which includes divergent thinking, generation of innovative ideas, originality, inventiveness, ingenuity and the ability to see opportunities to solve problems [25]. The final classification is presented below:

1. Methodological: M1) Problem solving; M2) Entrepreneurial thinking; M3) Efficiency in problem solving; M4) Decision-making; M5) Creativity; M6) Analytical skills; M7) Research skills; M8) Critical thinking; M9) Systemic thinking.
2. Technical: T10) State of the art knowledge; T11) Technical abilities; T12) Understand new processes; T13) Media skills; T14) Programming skills; T15) Understanding information security.
3. Personal: P16) Flexibility; P17) Complacency; P18) Tolerance; P19) Motivation to learn; P20) Sustainable mindset; P21) Ability to work under pressure.
4. Social: S22) Leadership skills; S23) Ability to commit and cooperate; S24) Master more than one language; S25) Ability to work as a team; S26) Communication

skills; S27) Networking skills; S28) Intercultural skills; S29) Ability to transfer knowledge.

The classes from the engineering department that already used any active methodology were chosen for this case study. To identify these classes was applied an unstructured questionnaire was applied to interview professors and select those classes which use active methodologies and had availability to participate in the research. Having made this selection, the survey forms were applied.

First the forms where submitted to professors, to identify what was planned to develop in students during the semester. Secondly, the same form was submitted to undergraduates, to collect what skills do they identify that have been developed in the course. For both, the development of twenty-nine skills was analyzed by five possible answers: The skill was very well developed (note 5); The skill was partially developed (note 4); I cannot identify whether this skill was developed (note 3); The skill was poorly developed (note 2); The skill was not developed (note 1).

To analyze the answers, identify the development probabilities of each skills and conclude what dimension were more “successfully developed”, a decision tree method was used, and an overview was proposed to synthesize the answer. And to analyze the correlation between professor and undergraduate viewpoints, the results were plotted by dimensions in radar charts. The case study and the conclusion about what Industry 4.0 skills are developed by active methodologies, are presented in the next section.

4. A case study in the University of Brasilia

To identify what Industry 4.0 skills are developed in the undergraduates, four disciplines from engineering degree was analyzed: Products Systems Projects 1 (PSP1), Products Systems Projects 2 (PSP2), Products Systems Projects 6 (PSP6) and Special Product Engineering Topics (SPET). Both disciplines use the PBL as the main methodology during all semester.

The objective of these courses is to develop solutions to problems based on specific disciplines that are related to each one. For example, in PSP1 students need to solve real problems using statistic disciplines as the anchor approach; in PSP2 students need to solve real problems using, as the anchor approach, informational systems; in PSP6 students need to prototype physical solutions to real problems based on product development as it’s anchor discipline; in SPET, students also need to prototype solutions based on product development, but with a low complexity level when compared to PSP6 (PSP 6 is more technical and focused in applying one specific methodology to solve a problem and develop a product). It's important to mention that both courses (PSP6 and SPET) prototype solutions to solve one problem introduced in the semester.

The first step was applying the questionnaires with the four professors, to understand their main expectations related to what was planned for the discipline and what they believe would be developed in undergraduates. About the undergraduates, a universe of 138 students participates in the research in the period of November 24 to December 13 of 2019. Figure 1 shows the results.

To PSP6 class, which had a total of 46 responses, students consider that in the methodological dimension, all skills were very well developed, except creativity and critical thinking (47%). In the technical dimension, students identified that the skills of state-of-the-art knowledge, technical skills, and understanding of new processes were very well developed, in contrast, media, programming, and understanding of information security skills were identified as undeveloped by 36%, 73% and 52% of students respectively. Following the personal dimension, all skills were identified as very well developed. In the social dimension, practically all skills students are well defined.

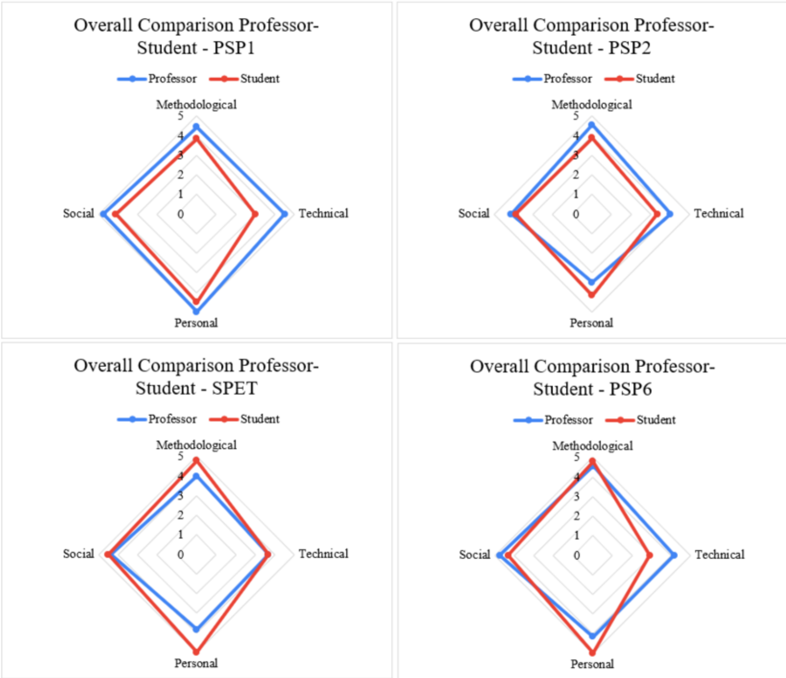

Figure 1. Overall comparison professor and student answers by discipline.

Analyzing the SPET class, in the methodological dimension, almost all skills are very well developed, except for entrepreneurial thinking and research skills, which were identified as partially developed by 67% and 47% of students respectively. In the technical dimension, 47% of the students point out that the programming skill was not developed, as well as the media skills and understanding of information security that did not have their development identified by the students. In the personal dimension, all skills were identified by 70% of the students as very well developed. This fact is repeated in the social dimension, except for the ability to develop a domain over more than one language.

The PSP1 has all methodological skills pointed out as partially developed (61%), except the ability of systemic thinking, whose development was not identified by the majority. In the technical dimension, state-of-the-art knowledge centers, understanding of new processes and media skills were indicated as partially developed. Technical skill was indicated as poorly developed. Programming and information security skills were indicated as undeveloped (62% and 38% respectively). In the personal dimension, all skills were identified as very well developed, except for flexibility, tolerance and motivation in learning, identified as partially developed. In the social dimension, the ability to develop a new language was identified as undeveloped, while for the skills for networking, intercultural and knowledge transfer, they were identified as partially developed and the rest were indicated as very well developed.

PSP2 discipline has all methodological skills pointed out as partially developed, except the ability to been creative. In the technical dimension, 37% of the students agree that the state-of-the-art knowledge was well developed, and about understand new processes and media skills, 40% agree that was partially developed. The majority pointed out that programming skills and understanding information security weren't developed. In personal dimension the majority was identified like partially developed, the same occurred for the social dimension, except for the ability to develop a domain over more than one language.

Looking at these answers it's possible to observe that exist some differences between what the professor identifies like "developed" and what the students really identify like "developed". To analyses and compare the differences between the two viewpoints and look at the relationship level of each ability answer, a correlation analysis was developed and was implemented a decision tree to identify what was the probability of development of each skill based on the answers. This analysis is presented in the next topic.

5. Comparing two viewpoints: professor and students

Having completed the analysis of the students and professors' perspectives, the decision tree method (Table 2) was used to classify the development probabilities of each skills, which shows that the most developed dimension in the four courses analyzed was the personal and social. The technical dimension was not much developed, except in PSP1. The methodological is the dimension with the lower level of development. The course with the biggest answer number was chosen to be detailed bellow (PSP6).

Table 2. Decision tree results: development probabilities of each dimension.

	PSP6	PSP1	PSP2	SPET
Methodological	20,75%	23,37%	21,35%	21,76%
Technical	24,62%	26,99%	22,50%	22,94%
Personal	27,64%	25,00%	27,88%	28,43%
Social	27,17%	24,64%	27,31%	27,84%

The PSP6 decision three results show that the dimension with the biggest development probability is the personal, with 28% of development chance of tolerance skill. With 27% of development probability is the social dimension and the ability to work as a team. With 25% is the technical dimension, with the probability of failure the develop programming skills. The methodological dimension had 21% of chance to develop the decision-making skills.

Analyzing the PSP6 discipline had the professors' perspective surpassed by what was actually developed by the students. In the methodological dimension, for example, only the creativity skill had a different professors' perception than the one expressed by the student, where the professor identified the skill as very well developed and the students pointed it as partially developed. In other dimensions the same fact occurs for understand new processes, media skills, understanding information security, networking skills and intercultural skills, and the greatest divergence occurred to media skills, pointed out by the teacher as partially developed and by the students as undeveloped.

6. Discussion and research agenda

In this paper the impact of Industry 4.0 in education and training of new professionals, mainly engineers, was evidenced by the understanding of the new skills that compose the ideal professional profile to future and the identification of how universities are preparing themselves to provide the skills needed by them.

A case study was applied in the University of Brasilia (UnB), to analyses four disciplines that use a transdisciplinary approach with the application of active learning as a method to develop the Industry 4.0 skills. The tools used for the analysis were the correlation level and decision tree.

Through these analyses and results of undergraduates answers, it's possible to conclude that even though the methods used to apply the transdisciplinary education in engineering training to developed skills for Industry 4.0 aimed to contribute in all four dimensions (methodological, technical, social and personal), some dimensions are more developed than others. In general, the skills development must be balanced and probably, if considering that during engineering graduation the disciplines, programs and courses have different development skills objectives, there are chances of developing all related Industry 4.0 skills, but this study does not allow to conclude this fact.

This last cited fact is not considering in the survey form used to analyze Industry 4.0 skills, they were generic, especially about the methodological and technical dimensions, maybe this is the cause of the differences between professor and student viewpoints since it could exist different interpretations about the meaning of each skill, once considered that they were generic.

Future work could be developed to propose a methodological application and analyses of Industry 4.0 skills in courses that use an active learning approach, considering skills development during all graduation and application of indicators that can prove undergraduates learning.

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Evaluation of the Impact of Open Innovation and Acceleration Programs on Research and Development Performed by Universities

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Abstract. Commonly-known for their sophisticated and robust results, and some lack of time-to-market orientation, the universities are reviewing their roles to be more competitive in the innovation ecosystems. The actual context is large growing of acceleration programs to promote Open Innovation in startups, as well as traditional corporations, interested in the development of innovation across organisational boundaries. Although recent studies emphasise that startups developed or supported by universities have more expectations of success than non-academic startups, the movement of acceleration programs with an emphasis on open innovation is not always connected to universities and supported for research and development. This fact indicates that there are opportunities to encourage the work of universities with companies and other actors for the development of market-oriented proposals and innovative solutions that cover different fields of knowledge through transdisciplinary research. This study has as main objective to identify practices and impacts of acceleration programs for open innovation and its relationship with Research and Development in universities. This study is conducted in two phases in order to analyse the impacts: the first is a systematic review of the literature to identify state of the art of the studied themes in a combined manner. The second phase of the article consists in study two application cases of acceleration programs at the Pontifical Catholic University of Paraná. The work aims to analyse the impacts of the open innovation and acceleration programs found in the literature and in the case study in order to identify opportunities for improvement for the programs of acceleration of open innovation which universities propose or participate. The expected result is to provide subsidies for universities to increase their participation and contribution in programs, to accelerate innovation and open innovation, supported by transdisciplinary and excellent research.

Keywords. Open innovation, research and development, university, accelerator programs.

Introduction

Among other stakeholders, manufacturing industries of different types are interested in sustainable innovation and depend on universities to satisfy the demand for qualified labour [4]. In order to satisfy the expectations of industries and also of society in general, universities are increasingly relying on transdisciplinary training and collaboration with different actors, such as the industry itself and the government to deliver innovative solutions [4] and [5].

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The arise of division in innovation labour which, universities specialise in research, small start-ups convert promising recent findings into inventions; and more substantial and more established firms specialise in product development and commercialisation [6]. Such fragmentation could lead to a player specialisation, therefore decreasing innovation diversity, competition and the societal impact of Universities' R&D [6]. However, this scenario is uncertain as long as a shift in the role of universities from education providers to scientific knowledge and technology producers in the current knowledge-driven economy [7]. In this context, in which companies and universities are collaborating through different types of work, new university roles are required [8]. The authors of the present work started studying the role of the university [9], especially the contributions of research, development and its impact on innovation.

In the relations between university-industry-government, there are some possibilities of knowledge transfer to generate innovation, among these modalities, three types of programs are studied in a combined way in this work: open innovation (OI) and acceleration programs (AP) in research and development (R&D).

According to the literature review carried out below, recent research on the theme development of ecosystems has increased. Many of these studies have been focused on results, methodologies, financial or social aspects, among other theoretical and practical aspects [10], [11] and [12]. However, it is understood that there is an opportunity to study research and development and its relationship with open innovation initiatives and acceleration programs. This study aims to identify the impact of acceleration programs and open innovation programs and their respective contributions to Research and Development at universities. To find the outcomes of acceleration and open innovation programs and their impact on research and development carried out by universities, a systematic literature review of the three topics of interest and analysis of two application cases in Brazil are presented as follows.

1. Background

The rise of technologies, sustainability opportunities, cost reduction and user experience, has produced a vast number of initiatives to offer incremental or disruptive innovations in their primary alternative forms: process, products and services, business models [13]. To this purpose, innovation partnerships and the sharing-is-winning model emerge intending to accelerate co-development of sustainable innovation, with the alignment of the entire value chain with consumer-centred innovations as one of its main pillars [11].

Universities play essential and different roles in entrepreneurial ecosystems, can play one of the actors in the innovation network, supporting research and development; as a channel for recruiting entrepreneurs or; as co-working spaces [14] and even more. In this way, the relationship between universities and industry is acquiring significant importance, supported by the knowledge-based economy and obtaining sustainability through knowledge transfer [15] and [16]. Moreover, when the topic specifically mentions knowledge transfer and innovation, there are several adaptations between industry and university for the closeness of work and the guarantee of better results for innovation [11] and [4]. Recently, a new definition of innovation ecosystems was proposed [17], compiling several previous concepts. According to the authors, an innovation ecosystem is the evolving set of actors, ventures, artefacts, organisations and relationships, including complementary services and substitute relationships, essential for the innovative performance of an actor or a population of actors [17]. In addition to the same concept, it can be said that business ecosystems can build a structural dynamic among various partners in the system [18]. These partners are listed as, but not only, start-ups, venture capital funds, government agencies, research institutions, and others; including the nature and dynamics of connections installed [18] and [20].

One way that innovation ecosystems work is through acceleration programs (AP), which in essence are intensive and limited-time educational programs that, through practical situations, develop teams composed of students, professionals, teachers and researchers, to make them able to grow your ideas on the field. In these programs, start-ups are selected according to predetermined criteria, and their founders receive support and guidance. In this way, their teams/start-ups are able quickly to be exposed to different types of mentors, such as entrepreneurs, angel investors, executives in order to attract resource for their start-ups to reach new levels of business maturity. The programs have a high point of presentation of start-ups to potential investors and other interested parts, called a "demo-day" where each participating start-up defends its project, known as "pitch" [19] and [20].

With the growth of business and university ecosystems, incubators and accelerators have become an integral part of that ecosystem needed to support the growth of new ventures [21]. An accelerator is a generic organisation that plays a crucial role in encouraging entrepreneurship and validating their respective ecosystems of business innovations. These initiatives guarantee a vital position in the development of technological and socio-economic advancement. [20]

Additionally, to the changes that are occurring in the ecosystems, the open innovation concepts are gaining space in the universities-industry relationship. The goal of open innovation is to reorganise innovation processes, taking knowledge flows across organisational boundaries [5], which means that more open sources of external knowledge have been proven to facilitate better results for innovation [22]. It is based on this concept, that every type of company works close to universities, government, suppliers and customers to gather new and unexpected knowledge to develop more innovative products, services and processes. In other words, OI practices can be extended to research and innovation management practice and its interactions with business ecosystems [22] and [23]. The concept of OI, supported by the classic Triple Helix, proposes interactions between university, industry and government as the pillar of innovation. In the Triple Helix concept, universities play an essential role in OI's contribution, as they are an essential supplier of knowledge in Research and Development (R&D) [23]. The practices of OI are now becoming more present in innovation activities in the university, industry and government, which has been shaping new approaches in the way as universities produce R&D, directly impacting the results of the innovation.

In this context, the present work aims to compare qualified literature and practical efforts to produce better results for the entrepreneurial ecosystem. While the university is considered as the main actor, the present work verified the adherence between theoretical studies and research practices, open innovation in an acceleration and development program in the entrepreneurial ecosystem.

2. Method

2.1. Systematic Literature Review

Based on the research methodology previously developed by [25], [26] and [27], a systematic literature review (SLR) was conducted in the present study in order to identify state of the art. A SLR is 'a systematic, explicit and reproducible method for identifying, evaluating and synthesizing the existing body of completed and published work produced by researchers, academics and professionals' [28]. With the analysis of the research problem, the authors selected three themes which better represented the research: Acceleration Programs (PA), Open Innovation (OI), Research and Development (R&D). Two stages, combining R&D with PA, and R&D with OI and its respective synonyms, were searched, keeping the focus in R&D as a central theme, with the inclusion of keyword University (UNI). These different combinations of keywords and synonyms were consulted in the Scopus and Web of Science (WoS) databases from 2009 - 2019.

The first search using the keywords, their combinations and synonyms found 204 articles, and after the exclusion of duplicates, the result was 161 articles. In the next step, all the articles that satisfied the following criteria were selected: articles in English, from journals with Q1 classification (according to Scimago Journal Rankings), resulting in 90 articles. The last step consisted of reading the title, summary and keywords in order to find only articles precisely related to the research topic, resulting in 16 articles selected for further study.

This section details all the content analysis of the 16 most relevant articles found in the literature. The content analysis was concentrated in reading the articles deeply to form the knowledge of the themes of acceleration programs, open innovation and research and development in the area, as described in details in Table 1. The table summarises the contribution of the 16 articles of the study showing the diversity of initiatives, interactions, models of work and outcomes from universities which search for R&D interactions with their partners regarding for Open Innovation and Acceleration Programs applied in two undergraduate programs at Pontifical Catholic University of Paraná (PUCPR) located in the south of Brazil.

Table 1. SLR content analysis.

Authons and year	Contributions	Limitations	Applications	AP	OI	R&D
Perkmann & Shildt (2015) [29]	Industrial participation in largescale scientific collaborations can guide scientific enquiry towards greater societal relevance.	Application in some fields of science. Pharmaceutical industry.	Blueprint possibilities for public-private research partnerships.	√	√	√
Smart et al. (2019) [30]	Application of Open Science as a pilar to Open Innovation and social improvement.	Open science implementation challenges.	Insights for more collaboration and polices between university-industry-government to foster science.		√	√
Guerrero & Urbano (2017) [31]	Effects of the links between enterprises with other organisations, or with universities and government for innovation performance.	Mexico context Innovation performance of Triple Helix.	Discussion about the entrepreneurial university model.	√	√	√
Arora et al. (2019) [6]	Division of innovation labour.	United States context.	Discussion about universities' activities in the innovation ecosystems.			√
Dezi et al. (2018) [7]	The shift in the role of universities from education to scientific knowledge and technology provider.	Italy context.	Discussion about the future of university role as a knowledge provider.			√
Van Belkum et al. (2019) [32]	Differences between academic and industrial R&D.	Diagnostic microbiology industry.	Possibility of replication of the comparison between other university-industry collaboration programs focused in R&D/R&I.			√
Lucia et al. (2012) [33]	Benefits of university-industry collaboration for all stakeholders, especially students.	Management challenges.	Improvements in curricula to match the professional reality Program management best practices.		√	
Breznitz and Zhang (2019) [34]	Identification of the main contributions of acceleration programs for students and startups.	University of Toronto context.	Replication of research instrument for other universities.	√		
Goduscheit & Knudsen (2015) [14]	The functioning and barriers for SMEs that are starting the collaboration with universities.	Startups results are not differentiated from the other SMEs.	Validation of hypotheses in Brazil context.		√	√
Howells et al. (2012) [8]	The success of informal and straightforward innovation programs.	Sample selection bias.	Redesign the role of universities and knowledge production.	√	√	√

Authons and year	Contributions	Limitations	Applications	AP	OI	R&D
Janeiro et al. (2013) [10]	The connections between service firms and universities.	Portugal context. Research subjectivity.	Further studies to identify industry-firm collaborations in Brazil.		√	√
Traitler et al. 2011 [11]	Innovation Partnerships and the Sharing-is-Winning model.	The study recommends culture change.	The development of business skills to foster open innovation for R&D.	√	√	√
Natalicchio et al. (2018) [12]	The leverage knowledge from diverse areas and how universities converge it in new technologies for energy production patents.	Use of patents as the only innovation measure.	Opportunities for developing impactful technological solutions through knowledge recombination.		√	√
Howells and Cheng (2012) [35]	The role of Higher Education Institutions in Open Innovation Systems.	United Kingdom context.	Advances in the collaboration university-industry. Time-to-market orientation.	√	√	√
Villasalero (2014) [36]	Technological capital accumulation in the Universities connected with Science Parks.	Spain context. Use of secondary databases.	Advances in selling technologies originated in Universities.	√	√	√
Gálan-Muros & Plewa (2016) [37]	Analysis of barriers and drivers for University-business cooperation.	European context.	The focus on barrier reduction. Identification of barriers and drivers to Brazilian ecosystems.		√	√

The impacts of acceleration programs and open innovation initatives in R&D found in the literature review are diverse. A variety of methodologies, university or industry approaches, makes it difficult to identify patterns of interactions in the ecosystem. Some characteristics of innovation is a non-linearity, and the combination of models of work, also found in SLR. In these 16 selected articles, there is the presence of different programs of acceleration which considered open innovation to foster R&D in the following approaches: industrial participation in largescale scientific collaborations [29]; effects of different links between enterprises with other organisations the role of the higher education institutions [35] and science parks in universities technological capital accumulation [36]. Two of these 6 articles show elements that match the acceleration programs. PIBIC Master match the literature that affirms that different links between actor may produce distinct innovation outcomes [31]. The PIBEP program matches the literature findings: the success of informal and focused AP [8]. Finally, both programs support and prove the change in the university role. The collaboration between university-industry has been generating great results over the years. However, to face the innovation and transdisciplinary context, the literature and the application cases prove the necessity of increasing the university actions between all entrepreneurial ecosystem actors to increase the impact of AP and OI in universities R&D.

2.2 Two Application Cases

This section presents two application cases that will analyse the impact of two acceleration programs at the Pontifical Catholic University of Paraná (PUCPR) in Brazil. The first program is called "Institutional Entrepreneurship and Research Scholarship Program – PIBEP" [38]. The innovative program was conceived in 2016 and focused on the preliminary stages of the creation of start-ups, such as start-up concept design. The main objective is to accelerate ideas of business to evolve to higher levels of maturity. The transdisciplinary teams are formed mainly by undergraduate, graduate or alumni students, to a comprehensive development of their start-ups [38].

The second program to be analysed called “Institutional Technological and Scientific Initiation Scholarship Program Combined Degree - PIBIC MASTER”. This program aims to accelerate undergraduate students with excellent scientific performance, to conduct their undergraduate studies in parallel with a master's degree to obtain both degrees at the same time. The program also offers the possibility of six months of national or international mobility, where the student can develop his research in others universities and organisations, experiencing external contacts through different networks of cooperation and immersion in other cultures [39] and [40].

In this context, the CIMO-logic, known for its contribution to the research organisation, has been adopted to facilitate the analysis of programs impacts (Table 2). The CIMO-logic encompasses four phases: Context (C), Type of intervention (I) Mechanisms (M), Results (O) [41]. The acceleration programs will be described by the CIMO-logic and evaluated for their interface according to the topics studied: open innovation and impact on research and development.

Table 2. CIMO logic applied to PIBEP and PIBIC MASTER – Combined Degree.

	PIBEP CIMO logic	**OI**	**R&D**
Context	• Flourishment of ideas and startups of students in different knowledge fields; • Demand for development of soft skills linked to the entrepreneurial profile; • Incubators and accelerators in Brazil require a minimal structured business to invest in startups;	Required	Optional
Intervention	• Teams formed by students from different areas (interdisciplinary groups) and different levels (undergraduate, graduate and alumni); • The program focus on the early stages of start-ups creation, like start-up concept design; • Three-month cycle program;	Required	Optional
Mechanisms	• Students develop one innovative idea to solve a customer/consumer need; • Students must present a minimum viable product (MVP) which means ideas transformed into business models, including prototypes; • Education and mentorship with specialized entrepreneurs;	Required	Optional
Outcomes	• Public presentation (Demoday) to investors; • Enterprises are running; • Patent registration; • Invitations for advanced acceleration programs outside the university;	Required	Optional
	PIBIC MASTER CIMO logic	**OI**	**R&D**
Context	• Student acceleration in strict sensu post-graduation environment; • Acceleration of development of high-value research for society; • Qualified internationalisation of students and faculty and their researches; • High level for Scientific, technological and innovation aspects criterion; • Transdisciplinary education; • Development of scientific skills;	Optional	Required
Intervention	• 12 to 36 months program master´s degree simultaneously to the undergraduate course with option up to 6 months of national or international mobility; • The program focus on scientific problem-solution; • Intense doctorate researcher supervision; • National and international collaboration; • High-quality research orientation; • Opportunity to Industry applied research;	Required	Required
Mechanisms	• Graduation program with a previous completed scientific program well succed; • Attendance of all master´s degree of the choosen area; • Students develop a scientific solution to a theoretical or real problem; • Intense reserch supervision; • Industry mentoring in case of university-industry collaboration; • Cultural immersion; • Peer review of research in different levels; • Research development and publication;	Required	Required
Outcomes	• Development of quality research with high value for society; • Accelerated formation of qualified human capital; • Employability; • Patents and publications;	Optional	Required

The programs have a different approaches and results. PIBEP is a short-term program that emphasises the development of new businesses based on open innovation. The acceleration proposal is to transform ideas into business in initial stages in more advanced stages, with the idea validation, external investment, resulting in results: public business presentations to investors, the start of business operations, patent registrations and participation advanced acceleration programs. The transdisciplinarity of the students' academic backgrounds, their different levels of education and the previous experiences of the teams combined to the active participation of the other actors of the program in actions such as educational training, mentoring, and the experience of other companies highlights the impact of open innovation in the program.

Startups accelerated by the PIBEP program can be supported by scientific research. However, this is not a required element. Teams can choose research and development as the basis of their startup and consequently obtain results that differentiate them from startups that have not decided by R&D approach. In addition to business development, the main objective of the program, publications and patents can result when teams choose to include research in development as part of their delivery. Participation in the PIBEP program enriches the student's experience while producing more complex innovation results, centred on the user, with greater market acceptance and, consequently, higher survival and success rates of the startups that passed through the program - demonstrating the direct impact of open innovation in the program.

The Combined Degree - PIBIC Master is an acceleration program that intensifies the academic experience in research, through the formation of human capital and the development of research with high quality and in a compressed time. The purpose of this acceleration program is to allow the student to complete his undergraduate studies simultaneously with the development of his master's research, combining the two degrees, and necessarily resulting in innovative and relevant research for society. Transdisciplinarity takes place between the different and complementary backgrounds of students and their research supervisors, through mobility between universities, in contact with companies. When the university-industry relationship is provided, new the areas of knowledge are required for the development of each research.

In the PIBIC MASTER - Combined degree program, several interactions take place between actors from the university and industry, with diverse contributions and directions for the development of research. Additionally, the option of mobility makes it possible to experience different cultures. All of these elements emphasise the open innovation character of the program in all its phases. Furthermore, considering the nature of the program, the impact of research and development to generate innovation is clear. The program does not have as obligatory a business development, and it must be considered that its scope emphasises research and development with the support of open innovation - however - the same student can participate in different entrepreneurship programs offered by PUCPR such as PIBEP.

Although the two acceleration programs have very different characteristics, both are directly impacted by open innovation and research and development that result in positive outcomes in the student's experience and their transdisciplinary professional education. The impact of acceleration programs is also positively distinguished by the actors who directly participate in the initiatives that also foster the development of the region.

3 Results and Discussion

According with the literature review, the universities role, in constant evolution encourages the interactions of the university with other enterprises, including innovation partners on a broader innovation intermediary-type model [35]. Even that universities give attention to patent management [34], the emphasis on the knowledge trade by selling its research conflicts with development based on open innovation [36].

The transformation of knowledge with open science practices in parallel to OI used by universities increases their societal impact, [29] and [30] including in education [33] and [32]. Some factors seem to influence on innovation partnership with universities: effectiveness and speed; [11], connections, funding, organisational culture, internal characteristics, resource availability, relationships [37] and geographical proximity [7].

Innovation leaders, larger firms, Knowledge-Intensive Business Service (KIBS) sector are more likely to use universities intensively. The higher the innovation-intensity level, the greater the firm’s reliance on universities. Moreover, larger firms tend to access universities more intensively [35] and [10]. This fact could be a barrier, especially to

SMEs, which have an excellent opportunity to work closely. However, it seems that universities should communicate better its benefits for innovation processes to enterprises of all sizes [35] and [14]. In this context, APs seem to be a great opportunity to Universities and SMEs to increase in collaboration. Firms that participate in acceleration programs have more robust performance in employment and product growth. [34]. Firms that spend time in APs, and whose director is a habitual entrepreneur, achieve a significant chance of experiencing growth, in particular, product growth, especially in emerging economies, where universities and research centres do cooperate with enterprises, producing a positive effect on their innovation performance. This effect is reinforced when the enterprise has a high-growth orientation [31], similar behaviour to start-ups, which could influence on University strategy and operation.

The acceleration programs PIBEP and PIBIC MASTER provided valuable insights about universities movement towards entrepreneurship practices. It promotes the value of universities acceleration programs for educational purposes but also to market-orientation demands, developing differents skils which will able the students to perform more significant and competitive roles in their professional lives.

The application cases show some common points with the literature, showing that there is a change in the role of the university from a model of industry-academic to the complex model where the university is a facilitator and mentor for businesses. Additionally, it is possible to realize the crescent growing relation between university and industry have been impacting economic, environmental and socially of the innovation ecossistem where they are located.

4 Conclusion

This article has superficially discussed the evaluation of the impact of open innovation and acceleration programs on research and development performed by universities. It can be observed in the study is that few articles analyse university performance regarding OI and R&D and especially AP and universities' R&D. In this way, it was clear that the literature focus was on success rates of firms that cooperate with universities than assessing universities contributions themselves. Universities have been approaching with different open innovation models in order to cope with the current dynamic environment. The knowledge base provided by literature and application cases has been shown that universities are in transformation.

Moreover, given the nature of the innovation, these processes are in constant evolution, but they also can be accelerated. Another critical point to be considered is related to the more complex social and economic environment, universities, commonly known as qualified education providers, have been moving to knowledge suppliers. However, some key factors will determine the success of this new role. It mostly depends on the universities commitment to reduce the distance between the academic environment and the market. In this way, PIBEP and PIBIC MASTER present themselves as a clear solution of the universities moving to focus on innovation and entrepreneurial approach.

This literature review highlighted several lacks of information due to its broaden outcomes, that provided excellent opportunities for subsequent research. Consequently, further studies are necessary to explore OI and AP integration deeply in innovation processes considering universities are the centre of the ecosystem.

With different contexts, interventions, mechanisms and results, the acceleration programs that served as cases of application of these in this study showed the ability of universities to adapt themselves when they adopt a culture focused on innovation in its different approaches, indicating new possibilities for the creation of other flexible programs able to match industry and new business development based on research and development. Although the research did not address the relationship with the industry itself, the authors believe that the universities transformations are going through in a knowledge-based economy and rise of the Fourth Industrial Revolution.

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evoDash – A Transdisciplinary Vision for an Education Platform and a Simulation-Based Vehicle Development Process

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Abstract. In the wake of environmental disasters and accelerating climate change the challenges facing humanity seem bigger than ever. In the public eye private transport and mobility are two of the most apparent fields in need of a sustainable evolution. Around the globe car manufacturers and developers of innovative mobility solutions are hard at work in shaping the future of transport and travel. Like many modern problems these fields require a transdisciplinary approach and collaboration of disciplines in order to design a solution. At Trier University of Applied Sciences, the student team proTRon has been building highly efficient mobility concepts since 2005 and developing the prototype for a law- and safety-compliant urban vehicle concept since 2015. In this industry-oriented collaboration project the students get the chance to work in a realistic environment emulating a vehicle development process, preparing them for a job in the mobility industry as the next generation of system developers and engineers with a transdisciplinary attitude. Within the framework of this project students acquire competencies in communication and cooperation as well as gain expertise in areas like sustainability, efficiency, and organization. This paper introduces "evoDash", a human-vehicle interface prototype for the urban vehicle concept proTRon EVOLUTION with a focus on usability and modularity. Designed and developed by students it is a software architecture based on Android and central part of a vision for a transdisciplinary education platform, which provides the foundation for future software and hardware development projects working towards an innovative and sustainable human-vehicle interface. The modular architecture of the platform provides the necessary interfaces and layout options for the functionalities that result from innovative ideas and student projects, embedding them into a usable and individually adjustable framework that will be subject to continuous iterations in order to optimize usability, safety and security. This paper proposes a simulation-based process model focused on rapid prototyping. It aims at providing a possible framework for transdisciplinary engineering projects and education.

Keywords. transdisciplinary, sustainability, usability, human-vehicle interface, human-centered design, higher education

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Introduction

Global challenges like climate change are further facilitated by an emerging world and those problems are becoming more and more complex and all-encompassing, so that simple multi- and interdisciplinary collaboration are not enough to deal with them anymore. Fields like transport and mobility in the light of sustainability as a guiding principle deal with problems and propose solutions that have a major impact on the society, the economy and the environment. Researchers and experts from social-sciences, economics, natural sciences and technical disciplines must work together in a forum of open communication using methodologies and tools that go beyond their original fields to come up with the solution to modern problems [1].

At Trier University of Applied Sciences, the student team proTRon has been developing highly energy-efficient vehicle prototypes since 2005 and shifting their attention to the development of a street-legal, urban vehicle, that is supposed to challenge the established understanding of individual mobility in the automotive industry by advocating that less is more [2]. Starting as an extra-curricular activity, it has developed into a course-credited, but student-driven project with high ambitions. In collaboration with various departments, students with a background in electrical and automotive engineering, computer science, economics or design can contribute to this vision of a sustainable future of mobility in an industry-oriented study environment.

In this context higher education has the freedom to be a playing field for bright ideas without the constraints of economic risk. Students are free to pursue creative and innovative ideas, while retaining the option to fail and learn from it. There is a certain advantage in not having to play it safe. As a result, this paper proposes a partial solution to the challenges of the changing automotive industry in the form of a contemporary human-vehicle interface prototype and ambitious visions for a transdisciplinary education platform and a simulation-based development process.

1. Transdisciplinary Innovation

Transdisciplinarity commonly describes a research strategy adhering to the idea of a unified truth or shared knowledge regarding the workings of the world, transcending the boundaries of separated disciplines and building on top of them [1]. Perhaps a more comprehensible understanding in the scope of practice-oriented engineering projects is that of high-level integration of methodology and processes of multiple – if not all – disciplines [1].

Modern technological advancements and solutions cross the boundaries of disciplines. A transdisciplinary approach involves open communication between all imaginable stakeholders and taking into consideration current state, goals and outcomes in the grand scheme of scientific, social and ecological interaction [1].

Such an approach is especially necessary in the context of sustainable development and manufacturing. Sustainability as the concept of future-proof planning and preservation is inherently a transdisciplinary field, due to the natural interactions between systems, manmade or not [3].

1.1. Transdisciplinary Engineering in Vehicle Development

In the past the development of a car mainly represented the organizational structures of the automotive companies and suppliers themselves [4]. Each department developed their domain-specific solution for a problem, with department A for example developing the engine control unit, while department B was responsible for the body control unit. Thus, functions were designed locally and isolated [4,5].

Bus systems were introduced to enhance wiring and ECUs, sensors and actuators were interconnected for the first time, enabling new distributed functionality, such as ESP or ABS [4,5]. Consequently, even the development of the electrical system of a vehicle became a highly multidisciplinary task combining the knowledge of mechanical, electrical, electronical and software engineers. In order to develop such vehicle functions it is essential that these people have the same understanding of the problem, processes and solution [6,7].

Already today, modern vehicles consist of several million lines of code and include up to hundred electrical control units. Due to the development towards connected and autonomous vehicles and the software being the major driver for innovations, the amount of software in the car is predicted to rise even more drastically [8,9]. Next to brand, exterior design and energy efficiency of the vehicle, build-in software is increasingly turning into a deciding factor in the customer's vehicle preference [9]. Therefore, automotive manufacturers have increasingly started to treat in-car software as yet another important distinctive feature of their vehicles. One main component in this is the human-vehicle interface. Car manufacturers have the opportunity to create a diverse, distinctive and on-brand way of interaction for their vehicles [9].

Besides the increasing introduction of software in the car, the amount of information technology in the automotive industry, such as through off-board computing, cloud computing, connected and shared mobility services will also increase [9].

Because of the increasing amount of such interconnected, distributed software-enabled functions the complexity is growing dramatically, which transforms it to an organizational challenge for the automotive industry to handle. Challenges such as autonomous driving, connected cars, electrical and shared mobility for a more sustainable, safer and comfortable driving pose complex problems. The automotive industry is currently facing the reality, that their established methods and structures are not sufficient anymore to solve these problems [6]. In order to develop ethical solutions, aspects like the legal position and urban planning have to be considered. The development process does not only involve car manufacturers, but also the government, the infrastructure and the society, making it a highly transdisciplinary field [6].

These challenges will continuously require established processes and methodologies of the automotive industry to change [8]. Most manufacturers currently do not have the in-house expertise to stay on top of these developments and are even more dependent on various suppliers in order to provide elevated customer experiences, find sustainable solutions for future mobility and reduce costs [8]. Therefore, they cooperate with IT companies or other car manufacturers to get the required know-how and combine resources in order to master these trends [10]. At the same time big OEMs are building up their own expertise in information technology through launching their own IT development centers, as to not risk becoming a mere platform supplier for the human-vehicle solutions of IT giants [10].

Even titans and rivals of the automotive industry like Daimler and BMW are joining forces on research and development for a more sustainable future mobility with shared platforms such as Charge Now, Park Now or the car sharing service Share Now [11]. The changing industry introduces challenging tasks, but also a high potential for new innovations.

1.2. Transdisciplinary Education

More than integrating disciplines and fusing methodologies, Transdisciplinary Education places a focus on promoting transdisciplinarity as a meta-discipline and as an open, scientific way of thinking, which takes surrounding systems and the shared knowledge between and above disciplines into consideration [1]. The goals of Transdisciplinary Education are to develop a standard as to what a transdisciplinary approach entails and to providing established measures for the transdisciplinary competencies of students [1].

Unfortunately, the pursuit of transdisciplinarity can be hard within the confines of the fragmented structure of higher education and academics. The education institutions are organized into departments, often competing with one another for resources. Students are expected to pick a field to specialize in and are hardly ever incentivized by the curriculum to think outside the box [12]. Even in multi- or interdisciplinary collaborations students are limited by the discipline-specific methodology taught in their monodisciplinary curricula [1]. This inhibition of a transdisciplinary evolution peaks with the discipline-specific structure of academic journals [1].

At the same time, student learning is changing as they are studying more individually based and at their own pace. The role of teachers in higher education is shifting from being the performing agent to providing the resources, background and environment for students and their individual study [3]. Students are more and more interested in learning how to work sustainably and research suggest that students benefit immensely from coupling teaching sustainability and transdisciplinarity, as they are naturally related [3].

The intertwined relation of the two concepts is apparent in education but can be observed in application as well [3]. Students need to be provided with a learning environment and context that facilitates their transdisciplinary development. Major changes in established and traditional structures are unlikely to be accepted, as they threaten the status quo [1]. Instead institutions are to be encouraged to pursue establishment of transdisciplinary competencies through workshops and department collaboration projects [1,3,12].

2. evoDash – a Concept for an innovative Human-Vehicle Interface

The student-centered vehicle development project "proTRon EVOLUTION" is such a collaboration project capable of teaching transdisciplinary competencies. The goal of the project is the development of a street legal and highly efficient, electric urban vehicle in the name of sustainable mobility. "evoDash" is a sub-project, currently helmed by IT students and originally intended as a regular display-based infotainment system, which has become an industry standard [13]. Now, the "evoDash" prototype sits at the center of our vision for a modern and innovative human-vehicle interface, that goes beyond entertainment, navigation and basic driving data. The main focus of both the project and the sub-project is sustainability and efficiency not only during usage of the finished product, but also in development and production. The industry standard for infotainment systems is big, heavy, overprized and resource intensive hardware that remains unused while the vehicle is not being operated. A more efficient approach is to move the processing power out of the vehicle where possible and into the driver's mobile devices. Those are often cheaper, lighter and have use outside the vehicle. By making the processing unit independent of the physical vehicle, upgrading the hardware becomes easier as the user can interchange mobile devices for linking up to the vehicle to stay up-to-date with developments in hard- and software. Because the development cycle of about three to four years for a car is much longer than the advancements in information technology, the car could be equipped with state-of-the-art technology even after start of production [7]. As a consequence, the lifecycle period of modern vehicles could be increased and value retained.

Obviously, redundancies, safety and security concerns need to be considered, but such an approach would considerably increase the sustainability and eco-friendliness of a new generation of vehicles. Furthermore, "evoDash" (ref. Figure 1) has become a vision for a human-vehicle interface focused on interaction, sustainability and individuality. The system could encourage resource-friendly driving by impacting behavior through optimization, gamification and emotion to train the driver and raise awareness for sustainable driving. Machine learning can play a role in optimization depending on driver, vehicle, route and taking into consideration vehicle attributes like recuperation, route details like height profiles and traffic, and driver goals like commute and a fun driving experience.

Figure 1. Display-based UI of the human-vehicle interface Android prototype "evoDash" with the climate control screen currently displayed on the right and dynamic driving data displayed on the left.

The application prototype itself was developed with the goals of high modularity, adaptability and individuality. As outlined above, the whole system is supposed to improve vehicle attractiveness, especially for a sustainable and low-comfort vehicle like the concept being developed by the proTRon team.

2.1. System Development Process for a Human-Vehicle Interface Application

When developing a human-vehicle interface various legal, safety and security obligations have to be considered. Accordingly, applications like “evoDash” have to be compliant with German Road Traffic Licensing Regulations, with the current speed being displayed at all times just being one of many stipulations. Additionally, it is important that the driver does not get distracted while operating the car and that the user interface remains unobtrusive [14].

As such, development of digital human-vehicle interface applications, such as the “evoDash” prototype, is a highly transdisciplinary task. Not only is the necessary skill set and expertise of multiple disciplines required for the development, but the whole system needs to be considered for every stakeholder. To ensure that the intended user benefit from the system and find it appealing, quality features like usability, performance, reliability and overall aesthetics need to be validated through an open forum made up of experts from multiple backgrounds [15].

Figure 2. “evoDash” demo on an Android tablet during a “rolling chassis” event on the left and the driving simulator “FaSiMo” during a test drive on the right.

There are numerous psychological and cognitive aspects of humans interacting with a system interface in a safety-critical environment, that also must be considered. The driver should be able to perceive information of the user interface easily and navigate through the system quickly and accurately to reduce driver distraction [14].

The key to a transdisciplinary development like this, is that the different stakeholders involved in the process are equally informed of the development status and have the same understanding of the system [6]. For “evoDash” graphical mock-ups and use-case diagrams and other design artifacts were created to evaluate and validate different usability and application scenarios among the stakeholders of the project to prevent misunderstandings and identify problems long before the first line of code was written [13,16].

Due to the fact that the physical test vehicle of the “proTRon EVOLUTION” is not ready to be put on the road, the driving simulator (ref. Fig. 2) at the University of Applied Science in Trier was used to test the current iteration of the “evoDash”-prototype with driving data from a simulated test track [17]. “evoDash” has been part of several events (ref. Fig. 2) at the University of Applied Science in Trier, where visitors had the opportunity to experience this human-vehicle interface prototype and provide feedback regarding its usability, which could then be implemented in the next iteration of the modular and adaptable application architecture as further outlined in section 2.3.

2.2. User Interface Guidelines for Vehicle Development

With respect to consistency, usability and accessibility, user interface guidelines for vehicle development were introduced into the process of creating the "evoDash" prototype. This approach was obligatory to be able to construct a quickly adaptable user interface. The challenge is to provide driving information and entertainment data in an efficient way so that users rapidly figure out how to operate the application.

These guidelines are not intended as rules or restrictions but rather as convenient recommendations to support the procedure of turning goals and requirements into an applicable design [18]. General design guidelines which are already established in modern mobile devices are often too abstract or not befitting the concept [18]. Even though these existing design guidelines generally differ in their intention and output, in our case they are suited as a structure that can be adapted to draft design guidelines, tailored to the system [13,19]. In the development of an application for a street-legal vehicle it is crucial to take passengers' safety into account.

One focus of our approach in the development of our user interface guidelines are the ten heuristics by Molich and Nielsen [20]. They provide a classification of usability problems, that influenced the user interface guidelines of the „evoDash" user interface. These classifications are quite similar to Google's Material Design [21]. Material Design describes the utilization of physical rules and flat surfaces to imitate materials that help the user indicate areas where user interaction is possible. The use of very graphical and bold elements guides the user through the learning process on how to interact with the given components. The simplicity of flat design has the function to enhance interactions with the system. Important information visually pops to draw the attention of the user [21].

Overall, the „evoDash" user interface guideline helped with building a consistent and user-friendly interface design that assists the driver in effectively interacting with the UI, while still adhering to the traffic regularities.

2.3. Transdisciplinary Education Platform

The student project "proTRon EVOLUTION" as a vehicle development project already unites many different disciplines in its vision of a light-weight, high-efficiency electric vehicle for private or shared mobility in urban areas. Contrary to the direction of the German automotive industry, which currently aims for luxury and comfort, the vehicle concept focuses on the "mobility" keystone: safe, reliable and affordable travel. This means sacrificing the comfort and luxury of the physical driving experience, making it even more crucial to add value and attractiveness through software and clever concepts.

Currently the development is mostly multidisciplinary in nature with students largely following methodologies taught in the curriculums of their respective departments. However, there are some sub-projects, such as the development of the „evoDash" infotainment concept that follow the transdisciplinary idea. After the completion of the test vehicle, automotive engineering as the driving force behind the project will only be able to generate little additional value through optimization.

Instead the focus of the project will shift towards electrical engineering and information technology and the generation of value through innovative software functions. In the context of driver experience design and vehicle performance optimization various disciplines like economics, social studies and environmental sciences play a part and while their perspectives are to be considered, the collaboration project "proTRon" is supported most strongly by the technical faculties. The shift towards software as the primary value generator for the product is an opportunity to create a transdisciplinary framework for an education platform, a pilot project for transdisciplinary work and the prototype for a vision of modern human-vehicle interaction. The focus of the overall project will then shift towards usability, individuality, data security, adaptive performance and energy optimization, vehicle information, driver interaction and attractiveness of the overall driving experience. All these issues have to be approached with a transdisciplinary mindset due to their multilateral nature, requiring student teams of different disciplines.

Innovative development, cooperation and competition with the automotive industry and practical education of the students for their future in the workforce remain the cornerstones of the project. It provides the students with an environment to develop skills in solving problems independently, responsibly, and sustainably, while being able to communicate and collaborate on them. Students are supposed to get the chance to try out new methods and pursue innovative ideas in a framework that promotes crossing the boundaries of the disciplines.

„evoDash", which was initially only envisioned as a regular infotainment system and dashboard display has evolved into a vision for modern human-vehicle interaction based on usability, individuality, emotion and clarity. In order to carry such a transdisciplinary vision into multi- and interdisciplinary working groups made up of students of different departments, the established methodologies and development models of the departments will not be sufficient. Due to that this paper proposes a novel process model, fit for vehicle development and its context, in the next section.

3. Transdisciplinary Development Model for simulation-based Prototyping

In order to develop a safe, functional and usable human-vehicle interface, design a fulfilling driving experience and optimize performance and efficiency per individual, multidisciplinary student teams in project "proTRon" require methods beyond the ones taught in the curriculum of their departments. Figure 3 proposes a process model that takes into consideration the transdisciplinarity that the project vision requires. Initially limited to mainly contributing disciplines, the model can be expanded upon contributors.

Several contextual factors, such as costs, safety and fragmented development cause the simulation-based nature of this prototype development model, fit around the development of the "proTRon EVOLUTION". Students from information technology, automotive and electrical engineering work together in tandem to translate the shared, common knowledge and innovative vision into discipline-specific components of an interactive system. The inner loop iterates in a simulation environment before deploying into the outer loop and onto the physical test vehicle as a prototyping platform. There, the system gets validated and updated requirements lead back in an agile fashion into the inner loop for the optimization of interaction, usability and sustainability. Eventually the first iteration of a finished vehicle can be deployed, while iterative development continues.

Obvious use-cases for this approach include the implementation of machine learning for adaptable optimization of range, energy-consumption and performance based on the individual vehicle, driver, or route. It also provides a framework for fine-tuning driving experience and human-vehicle interaction. There is an opportunity to develop a system that influences the driver's behavior towards sustainable driving based on the sensory self-perception of the vehicle and the dynamic and context-based relay of information.

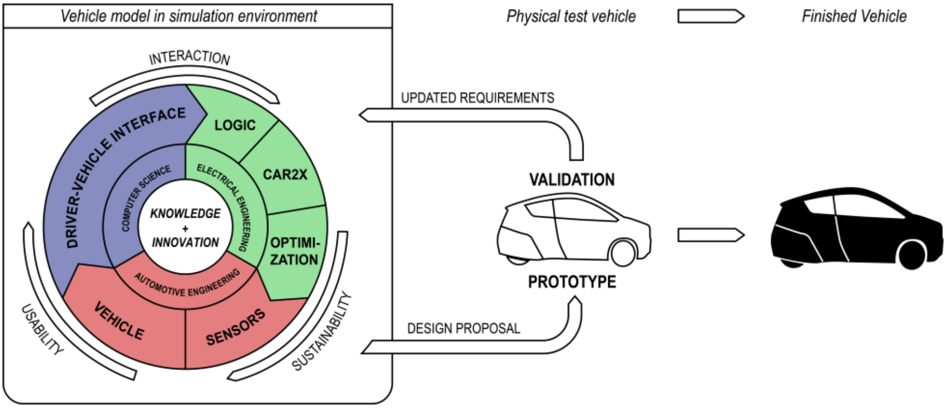

Figure 3. Process diagram of a simulation-based prototype development model in a transdisciplinary project environment with multiple departments collaborating.

4. Conclusion

"evoDash" is a promising vision for modern human-vehicle interaction, especially in the context of sustainability. At Trier University of Applied Sciences, it is part of a platform that encourages students to develop transdisciplinary competencies through multi- and interdisciplinary teamwork and collaboration towards a common goal. The paper presents a student project, which aims for competitive innovation without being tied to the typical industrial framework. The freedom gained in the development of open solutions shows how the described transdisciplinary approach can be successfully implemented. The procedure model presented combines agility with prototypical quality assurance without restricting its flexibility.

Just recently established as a project platform, "evoDash" is already providing a framework for several student projects in the IT department. Those projects focus on the link between the vehicle systems and the user interface, such as radio or context-driven navigation and subsequently cross over into fields such as automotive and electrical engineering. Only time will tell if "evoDash" proves successful in its educational goals, but based on the results and environment the "proTRon" project provides on the engineering side, we are confident in the benefit "evoDash" provides for our students.

The conceptual ideas and innovations regarding "evoDash" must also pass the proof of time. Nevertheless we believe in this respect that established car manufacturers will run into problems in the future with the wide variety of proprietary user interaction hardware/software and will have to take other paths, perhaps similar to the one pursued here.

Acknowledgement

Sincere thanks to all the members of the projects "proTRon" and "FaSiMo" at Trier University of Applied Sciences for their support and feedback. Special thanks also to the co-authors of "evoDash": Jonas Reetz, Sascha Reinshagen and Damir Zinn.

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Industry 4.0, Methods and Tools

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Digitalization and Big Data in Smart Farming – Bibliometric and Systemic Analysis

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Abstract. Agriculture has always had a great significance in the civilization development. However, modern agriculture is facing increasing challenges due to population growth and environmental degradation. Commercially, farmers are looking for ways to improve profitability and agricultural efficiency to reduce costs. Smart Farming is enabling the use of detailed digital information to guide decisions along the agricultural value chain. Thus, better decisions and efficient management control are required through generated information and knowledge at any farm. New technologies and solutions have been applied to provide alternatives to assist in information gathering and processing, and thereby contribute to increased agricultural productivity. Therefore, this article aims to gain state-of-art insight and identify proposed solutions, trends and unfilled gaps regarding digitalization and Big Data applications in Smart Farming, through a literature review. The current study accomplished these goals through analyses based on ProKnow-C (Knowledge Development Process - Constructivist) methodology. A total of 2401 articles were found. Then, a quantitative analysis identified the most relevant ones among a total of 39 articles were included in a bibliometric and text mining analysis, which was performed to identify the most relevant journals and authors that stand out in the research area. A systemic analysis was also accomplished from these articles. Finally, research problems, solutions, opportunities, and new trends to be explored were identified.

Keywords. Agriculture, smart farming, intelligent systems, smart technologies

Introduction

The agricultural sector has been improved with the arrival of the fourth industrial revolution [1]. New technologies and solutions have been applied to provide alternatives to assist in the collection and processing of information, contributing to the increase in agricultural productivity [2].

In recent years, technological development has introduced radical changes in the agricultural working environment (i.e., the use of electronic systems and data transmission). Besides that, these changes required the provision of updated information on systems, equipment, markets, and agents involved in production for the strategic and managerial decision-making processes [3].

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Agriculture 4.0, as well as Industry 4.0, represents the combination and interaction of internal and external agricultural operations, enabling the use of detailed digital information to guide decisions along the agricultural value chain [4]. Also, in this context, the concept of Farm 4.0, or smart farm, emerges in the search for ensuring that a property is endowed with equipment, processes and people targeted to digital agriculture [5].

In addition to the introduction of new practices and tools, Agriculture 4.0 has as one of its main objectives the adaptability of production systems and the improvement of efficiency [6]. The latter occurs through increased productivity, which is the ability to collect, use and exchange data remotely in real-time [7]. Thus, automation and intelligent decision making become very important for the fulfillment of these objectives [8].

The development of information and communication technologies, IoT(internet of things), cloud computing and Big Data, is leveraging the development of smart agriculture [9]. Through the combination of technologies that make use of cloud computing and IoT, digital agriculture is evolving, as it is possible to take advantage of the immense amount of agricultural data generated by the operations carried out on the farms [10].

Big data technologies are being used to provide predictive information in agricultural operations, allowing real-time operational decisions to be made and redesigning business processes. These technologies play an essential role in the development of a scenario in which humans are only involved in high-level intelligence analysis and action planning [9].

Given these technologies that encompass smart agriculture and its applications, this article aims to verify the knowledge and previous studies on the subject. Thus, a bibliometric and systemic analysis based on ProKnow-C (Knowledge Development Process-Constructivist) was conducted to find out about the work already done, methodologies, technologies and tools used, and to identify gaps in the literature on the subject in question.

Section II presents the methodological aspects of the research, followed by the presentation of the sequence of activities to carry out the selection of the bibliographic portfolio in section III, as well as the bibliometric analysis and the systemic analysis in sections IV and V, respectively. Section VI presents the final considerations.

1. Methodological Aspects

Proknow-C was adopted as a methodological procedure. This instrument defines a flowchart for bibliometric review and is designed to assist researchers in managing information and knowledge in relevant content on a specific scientific issue [11].

The structured literature review process is a fundamental tool, since currently there is a huge availability of information,and whichis used to manage the diversity of knowledge in academic research. It is possible to map and evaluate existing knowledge and define a research question to further develop existing knowledge when carrying out a structured literature review [12].

ProKnow-C consists of the following steps: selection of the bibliographic portfolio, bibliometric analysis, systemic analysis of the portfolio, and definition of the research question and objective [13]. These steps are shown in Figure 1.

In selection of the bibliographic portfolio step, the research axes and keywords are defined, as well as the databases and, subsequently, the researches. The bibliometric analysis step defines which authors, articles, journals, and keywords are relevant to the research question. Finally, the systemic analysis interprets the articles in the bibliographic portfolio.

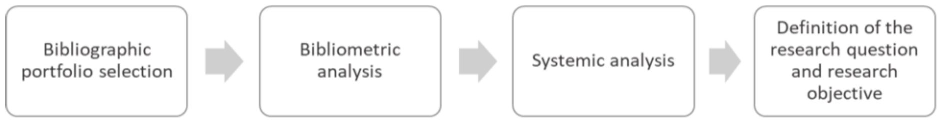

Figure 1. ProKnow-C steps.

This article will address only the first three steps of ProKnow-C, as this study aims to present the state of the art and research opportunities based on the systemic analysis step. To achieve this result, the software *EndNote*, *Mendeley*, and *Microsoft Excel* were used. *EndNote* and *Mendeley* supported bibliography management while the data tabulation was performed in *Excel*.

2. Bibliographic portfolio selection

The bibliographic portfolio selection aimed to gather publications with relevant content and scientific recognition related to the research topic. Figure 2 represents the steps for this selection.

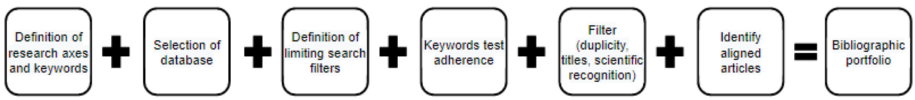

Figure 2. Steps for selection of bibliographic portfolio.

2.1. Research axes and keyword selection

The keywords used were divided into three categories (research axes): (*i*) Agriculture; (*ii*) Digitalization; (*iii*) Data Analysis.

Afterward, the keywords were combined into a search sentence with the booleans: ((“farming” OR “agriculture” OR “agrobusiness” OR “crop” OR “harvest”) AND (“digitalization” OR “connectivity” OR “CPS” OR “cyber-physical system” OR “iot” OR “internet of things” OR “data acquisition”) AND (“autonomous monitoring” OR “autonomous decision” OR “decision making” OR “knowledge-based” OR “data mining” OR “data analytics” OR “data modeling” OR “data processing” OR “data analysis”).

2.2. Selection of database

In order to have access to a wide variety of academic and conference publications, research databases were chosen considering their connection with the engineering area, as well as their availability in the CAPES (Higher Education Personnel Improvement Coordination) journals portal. The bases chosen were: Engineering Village, Scopus, ProQuest, Springer, Emerald, Web of Science, Willey, Science Direct, EBSCO, IEEE, and World Scientific.

In the Emerald, Willey, Science Direct, IEEE and World Scientific databases no articles compatible with the topic were found, therefore, these databases were excluded from the process.

Table 1 Research Axes and their Keywords.

Research Axes	Keywords
Agriculture	*farming* *agriculture* *agrobusiness* *crop* *harvest*
Digitalization	*digitalization* *connectivity* *CPS* *cyber physical system* *iot* *internet of things* *data acquisition*
Data analysis	*autonomous monitoring* *autonomous decision* *decision making* *knowledge based* *data mining* *data analytics* *data modelling* *data processing* *data analysis*

2.3. Collection of articles

The initial search resulted in a total of 2401 publications. Only papers from congresses and journals published in the last five years (2015 to 2019) were considered. Also, adherence to the keywords was accomplished by reading the titles of the papers. Three articles were identified related to the research topic and it was found that the keywords were also related to those previously defined.

2.4. Filtering

In this step, all references were exported to *EndNote X7* and *Mendeley* software, as these tools assist to handle this big amount of references. To further refine the results, all duplicate references have been removed, resulting in 2260 papers.

Despite the pre-selection carried out directly in the databases, the presence of 13 references from previous years to those considered in this study, as well as 93 references from other types of references and documents from other areas that were not of interest (Medicine, Biology, etc.), leaving 2154 references.

Thereafter, an individual analysis of each paper was conducted. Each of the 2154 titles in the portfolio was read, and only 183 were related to the research. Then, the number of citations for each paper was verified to identify the scientific recognition of the papers. The criteria for selecting articles for the next stage of the analysis was that it should be cited at least once. Papers published ast year with related titles that were not cited were also considered. Thus, 153 references remained.

The last step started with reading and evaluatingthe abstracts, to select the papers that were in fact related with the research. Thus, a total of 39 papers were selected for the final review. These steps can be analyzed in Figure 3.

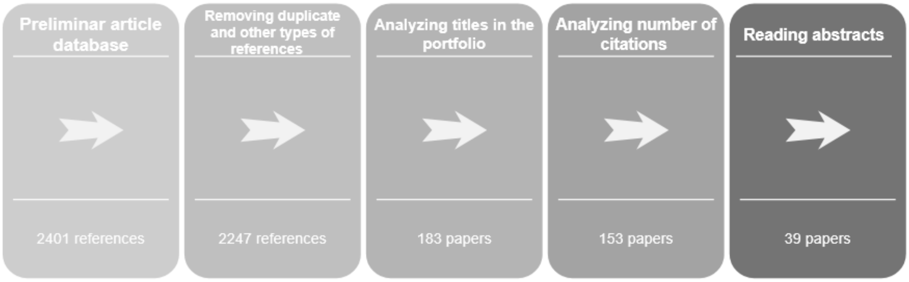

Figure 3. Steps followed to select bibliographic portfolio

3. Bibliometric analysis of bibliographic portfolio

Bibliometric Analysis allows to evaluate and interpret the bibliographic portfolio throughstatistical analysis, in order to generate knowledge of the bibliographic portfolio characteristics [13].

First, the results found for each database were analyzed (Table 2). In a total of 2401 papers, in Springer was found the large majority of articles, followed by Scopus, Web of Science, Engineering Village, ProQuest, and EBSCO. Databases as Wiley, Emerald, Science Direct, IEEE, and World Scientific didn't return any results.

Table 2. Returned articles per database researched.

Database	Number of articles returned
Springer	1370
Scopus	467
Web of Science	206
Engineering Village (COMPENDEX)	180
ProQuest	153
EBSCO	25
Wiley	0
Emerald	0
Science Direct	0
IEEE	0
World Scientific	0
Total	**2401**

It is possible to identify the year of papers' publication, the relevance of journals and congresses on the research topic, as well as the authors who stand out most in the research areaof the portfolio.

The total number of articles in the portfolio published per year is shown in Figure 4. When analyzing the year of publication, it can be identified that the year 2018 has more publications, in addition to nine papers already published in the year 2019, so it is said that the number of articles published anually is growing, and this topic remains prominent.

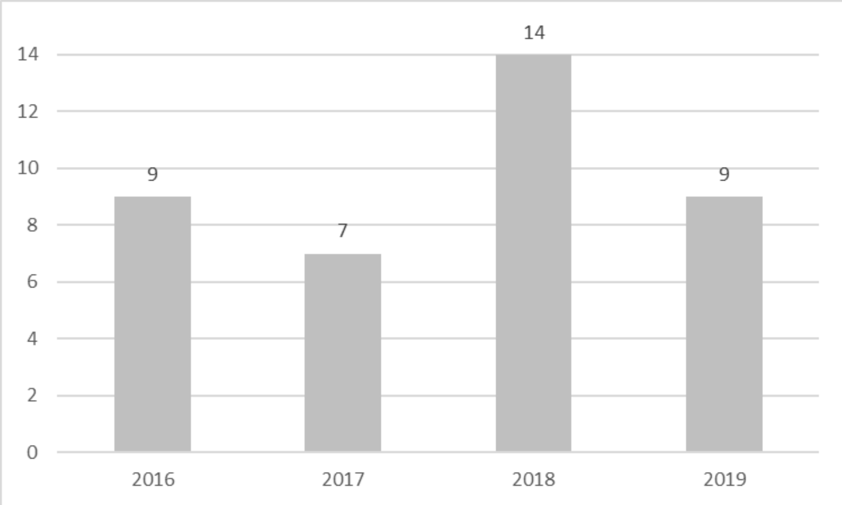

Figure 4. Number of articles published per year.

Continuing the analysis, with the exception of the authors Olakunle Elijah, Joseph Walsh, Sahitya Roy, Tharek Abdul Rahman, and Igbafe Orikumhi, who have two publications in the bibliographic portfolio, most of the publications were written by different authors.

Table 3 shows the ten most cited articles for this research. The most cited paper, [9], conducted a literature review on Big Data applications in Smart Farming and identified the related socio-economic challenges. The authors have also developed a conceptual framework for analyzing the topic that can be used for future studies.

The work of [14], [15] proposed intelligent monitoring systems to control environmental factors, such as humidity and temperature, and weather forecasting, using android, IoT and big data platforms. [16] in their article, proposed a semantic framework for smart agriculture applications based on IoT, which supports reasoning about many data flows from heterogeneous real-time sensors .

Table 3. Most cited articles[1].

Title	Citation	Year
Big Data in Smart Farming - A review	391	2017
Publicising Food: Big Data, Precision Agriculture, and Co-Experimental Techniques of Addition	65	2017
Intelligent Agriculture Greenhouse Environment Monitoring System Based on IOT Technology	65	2016
Internet of things: from internet scale sensing to smart services	57	2016
Big data in precision agriculture: Weather forecasting for future farming	54	2016
Agri-IoT: A Semantic Framework for Internet of Things-enabled Smart Farming Applications	52	2016
An Overview of Internet of Things (IoT) and Data Analytics in Agriculture: Benefits and Challenges	44	2018
Mobile Cloud Business Process Management System for the internet of things: A survey	40	2016
Scientific development of smart farming technologies and their application in Brazil	33	2018
How data analytics is transforming agriculture	29	2018

[1] October, 2019

After this step, systemic analysis stage started, which is presented in the next section.

4. Systemic Analisys and Review Discussion

The systemic analysis stage analyzed the content of the articles according to pre-established criteria. To complete this step, it was necessary to download the full texts, as only the citations were imported into *EndNote* and *Mendeley*.

To conduct the systemic analysis, each article was read in order to define the following aspects: (i) objective, (ii) methodology, (iii) main results, (iv) future recommendations, (v) research opportunities pointed out by the authors; and (vi) research opportunities found through critical analysis. This information was organized in an Excel spreadsheet and data were tabulated to facilitate global analysis.

When analyzing the articles, most of the tools and systems presented use IoT and big data to address issues involving aspects such as irrigation, pest control, crop growth, and weather forecasting. Some works like the [17] developed applications to support the interaction between IoT devices from different suppliers, seeking to recommend plants to increase agricultural productivity in a given location.

Several authors have tried to understand how the concepts of smart agriculture are being applied and what technologies are involved. Some works proposed solutions based on the development of IoT platforms, such as the study [18] that integrated IoT in agriculture. The authors considered a sugarcane plantation as an object of study and compared optimal parameters, regarding soil and environmental factors that should be considered to guarantee the maximum yield of the planting, with the captured data.

Other authors have created solutions based on the study of environmental factors to improve crop yields. [19], [20], and [21] implemented IoT technology to capture data for crop and soil monitoring, climate, and air monitoring, as well as machine work monitoring. According to [22], the majority of research involving IoT applications is focused on water management on farms, due to a lack of abundance.

[16] created a customizable online platform, based on IoT, that allowed large-scale data processing, analysis, and interpretation of data from different sources, such as sensory systems, surveillance cameras, climate and information, warnings, and alerts from government organizations. Although the platform seeks to integrate data from different sources, it is not flexible and adaptable to all agricultural scenarios and deals only with data from environmental factors.

The system proposed in [23] is based on IoT and is supported by a mobile interface, and seeks to create a connected agricultural network to share knowledge among farmers. The model proposed in [24] also uses the IoT approach for data acquisition via sensors, task control, and data management and analysis that are considered in the development of its system to help farmers manage aspects related to environmental factors and distribution information. [25] created a platform using CPS and IoT, capable of handling the needs of soilless culture in full recirculation greenhouses, using moderately saline water.

Although there are studies for the development of IoT platforms aimed at agriculture, they are specific to certain cultures and information. Thus, it is necessary to create generic platforms that can support any type of farm, regardless of their cultivation, being easily customizable and free from geographical restrictions [21]. According to the authors, it is necessary to develop IoT devices that take into account algorithms with advanced encryption, to increase the security of the captured data.

Big data technologies can be considered as the solution for various applications and can be used in decision making and to extract new ideas and knowledge for agriculture. The main challenges are to discover knowledge and correlations of historical records and deal with unstructured data [15]. In their research, [15] aimed, through the use of different data sets, to improve the accuracy of rain forecasts, using different parameters.

Big data applications in agriculture are not strictly related to primary production but play an important role in improving the efficiency of the entire supply chain to minimize production costs [9]. [26] used predictive big data analysis techniques to analyze and predict harvest yield and decide the best harvest sequence based on yield information from previous crops on the same land, current information on soil nutrients, as well as predict the cost involved with fertilizers.

Farmers are interested in business models that support the generation of revenue from data captured using IoT technologies [27]. From the data collected and generated by the various communication devices and technologies, it is possible to build knowledge bases that store complex and unstructured information. However, having a model that has information in an organized and complete way, that provides relevant knowledge, that can be used universally and that actually implements smart agriculture, is still a challenge [28], [29].

Through reading the articles and the critical analysis carried out, some research opportunities were achieved. Five of them can be highlighted:

- Farm 4.0 characterization, with all technologies and information flows presented;
- Generic IoT platforms for agriculture creation;
- Development of IoT devices that take into account algorithms with advanced encryption;
- Development of a universal information model to implement smart agriculture;
- Event prediction considering all factors involved in the agricultural scenario.

5. Conclusion

The present work developed a structured review of the literature on smart farming, aiming to identify research trends and opportunities related to smart farming. The ProKnow-C procedure was applied with the objective of raising bibliographic and systemic analyzes of the proposed theme. From an initial survey of 2401 publications presented between 2015 and 2019, a portfolio of 39 articles was identified as representative for the given analysis.

Through bibliometric analysis, the portfolio was interpreted and evaluated. It was possible to identify a growing interest in the subject. In the systemic analysis, all papers were read in order to identify the main research problems addressed, the proposed objectives and resources, and future research opportunities.

This methodological procedure proved to be adequate for the literature review, however, the correct choice of keywords used in the searches is extremely important for the correct representation of the research topic. Besides, when using ProKnow-C it is necessary to record each step performed, which makes the process difficult. It is recommended in the future to carry out all the steps again, including the analysis of the references of the papers that make up the bibliographic portfolio and ensuring the analysis not only of the most recent articles.

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Traceability of Information to Identify Nonconformities in the Production Process: Preliminary Study Production Process Optimization

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Abstract. For a company to compete in today's market, it needs to invest in developing project management tools to help improve its materials, products and production processes, reducing costs and continually improving its activities. This article aims to present the preliminary study performed to implement a custom semantic model in a technology company, which will enable the analysis and diagnosis of the production model to check nonconformities and to track information and materials, aiming at improving its production process and thereby raising its level of competition in the market. The preliminary study corresponds to the first of two phases of project development, which consists of the study carried out in the company to identify improvement needs for implementation of the analysis and diagnosis tool in the production process. For this, a tool development model is being developed with the mapping and the proposal of the model with its implementation strategy. Thus, it was verified that there is a disconnected traceability between the company sectors, information lost at the end of each process step, which eventually increases the time spent in each process phase. To solve this problem, resources were selected that, when integrated, will allow the integration of resources that were not previously connected in the company, in addition to reducing the time spent to close the cycle: connect, collect, analyze and act, making the response of production process activities in real time, seeking the optimization of production.

Keywords. Traceability, Production Process, Decision Making

Introduction

For a company to be competitive, it is necessary to invest in the development of modern project management tools, to improve materials, products and production process, while reducing costs and aiding the continuous improvement of activities. Even with the beginning of the digital revolution, industries have used few technologies for the production routine, leading to few success stories to certify available opportunities [1]. The use of smartphones, tablets and wearables is accelerating the use of mobile man-machine interface technologies, when these technologies are combined with accesss to data and information, they can make operators and teams more productive asa with the access to cloud technology makes it possible to share information more easily and quickly, through a web application [2]. This new context optimizes the control of the

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manufaafctuirng processes, while using Industry 4.0 insights on productivity, as it considers the monitoring and customization of the production line and simultaneously considering the reduction of costs, contributing to increased competitiveness.

It is believed that the reason for companies to use few technologies for the productive routine, is in most cases, the need for extreme changes, and in some cases changing the entire infrastructure of the production line, which leads to a period of adaptation to the new system, resulting in a decrease in productivity and profits. In this context, a study will be developed, using industry 4.0 concepts, to implement a system to optimize the production process in a brasilian capital and technology company established energy systems sector manufacturing uninterrupted power systems (UPS) and voltage stabilizers, with minimal interference and cost to the company. The project will be developed in 2 phases, starting with the preliminary study, followed by the application of system and the analysis of the results.

This article aims to present the study carried out to develop the towards for a computational tool for managing the production process of a technology company. This article presents the entire study developed to analyze the real needs of the company is gathered so that the requirements for the tool can be determined. The preliminary study of the optimization project of the production process seeks to analyze all the steps and responsible departaments of the company to make a diagnosis, where positive points and opportunities for improvement will be identified, as well as a detailed mapping of each sub-process alongside the integration processes of all activities. During the initial analysis, it was verified the need to develop a computational tool to evaluate the system's model of decay to verify nonconformities and identify opportunities for improvement, where the multiple perspectives involved in the manufacture of the product and the restrictions existing in the company, has compromised the quality of the production process, resulting in higher costs.

In this way, this article will initially present an overview of the Production Process Optimization Project, followed by the research methodology used to support the preliminary study, the results of a bibliographic research to identify tools to support the effective application of the principles of transformation of the raw material and energy in products. The following is an overview of the company's production process, as well as the positive and negative points raised during the field research, resulting in a diagnosis of the current situation of the productive process of the company. the diagnosis was made possible by the field research carried out in the production line to observe, collect, analyze and interpret facts and phenomena, allowing to raise among existing approaches used in the company's factory floor, here called Company Y. With that, it was possible to elaborate a structure of diagnosis and analysis of the production model to determine the solution strategy to be adopted. To conclude, the final considerations will be presented with the application of the first preliminary study phase, followed by the next steps to be taken for the implementation of the Production Process Optimization Project.

1. Bibliographic Research

The RBS Roadmap [5] was used partially for the accomplishment of the bibliographical research,. The RBS Roadmap has three phases: input, processing and output. The script was used partially because this study will perform a review of the literature and not a more complex research as a systematic review. The input phase, which will be used by this study, has 8 requirements to guide the research, see Table 1.

Table 1. Requirements for the entry phase of the RBS Roadmap (Source: the authors).

Requirements	Specification
Problem	It is possible to construct a semantic model customized for a company that allows the analysis and diagnosis of the company's current production model and check nonconformities, as well as identify opportunities for improvement in the product production process.
Goals	Gather information during the production process using technologies that allow the fusion of the physical ande digital worlds, to exchange data in real time, leading to the development of a computational plataform that will gather information during the production process, characterizing the traceability of information. To identify nonconformities during the production process and achieve a faster response to the problem, decreasing the time for decision making, seeking to provide a holistic follow-up of the process for analyzing the continuos improvement of production.
Primary Sources	"Product Engineering "Process Engineering" e "Tool".
Search Strings	Related words: "Appliance". The term "Tool" is at the center of the relationship, combining with the terms "Product Engineering" and "Process Engineering".
Inclusion Criteria	The research was carried out in the CAPAES/MEC periodicals portal. Type of material: articles; date of publication: last two years; only reviewed articles by PARES.
Qualifying Criteria	Approaches (primary or secondary subject) using support tools for the development of process engineering.
Method an Tools	Steps 1 to 4 of the interactive procedure of the RBS Roadmap processing step
Schedule	The survey began in the last quarter of 2018 and ended in the first quarter of 2019.

After defining the requirements to use the script (see table 1), the search was performed in the Portal of Periodicals CAPES/MEC. The portal has a collection with more than 38 thousand titles with full texts and 537 reference bases. Then filter 1 was performed, with the reading of the title, abstract and keywords, totaling 74 articles. With filter 2, the introduction and conclusion were read, reaching the number of 29 articles, ending with filter 3, with the complete reading of each article, resulting in 10 articles, the listed articles.

The 10 selected articles brought contributions and new questions about innovation, performance improvement and business environment, which will be discussed in the next section.

2. Results of Bibliographic Research

With the Bibliographic Research it was possible to see the need to understand the data processes, as key components of the system, from the data capture until its conversion into useful information during the manufacturing processes [1], while offering alternatives for storing a greater number of information for a faster analysis and consequently increase in productivity [14]. In this respect, one can consider the information, as “the formatlization of an exchange of one or more project data among stakeholders” [11].

Currently, in the business environment there is a great dynamism and the digital frontier, in the form of IoT, presents itself with great potential for the process industry [1].

The assembly process of the product is one the most important manufacturing activities, where the design, engineering, manufacturing and logistics processes are combined efficiently and economically [7]. Its importance comes from the fact of consuming up to 50% of the total production time, which represents more than 20% of the total manufacturing cost [15].

Therefore, manufacturing managers seek to monitor the performance of their operating processes to make the most profitable decisions in the short and long term. However, these decisions are related to na occasional offline analysis or comparisons with simple standards in custom worksheets, taking more time to generate and analyze basic information for effective responses [2]. An analysis of this limited system can cause problems in engineering and business as the system grows, hampering the ability to make good decisions at the system level [16].

In this context, a principle of information management (Closed Circuit Principle) and of recource reuse and integration (Recominant Innovation) were identified in the literature, and were defined as key points to be worked on during the systems development. These principles focus on the improvement of the process already used, considering unconnected resources and the reduction of the management loop without proposing drastic changes that require a linger period for adaptation. In addition, to considering the Mcmullen & Wiley [2] statement also points to the need to use modeling data convergence with cloud storage in order to enterprise’s systems achieve higher quality and data fidelity while minimizing errors and costs.

2.1. Closed Circuit Principle

To improve the performance of a process, it is necessary to monitor its performance indicators and to detect any deviation from the defined objective, understanding the process context to evaluate options in order to take the most appropriate corrective action to ensure that the solution is used correctly [2].

Still according to Mcmullen & Wiley [2], there are four steps of the information management loop: connect, collect, analyze and act, which represent the basis for problem analysis and solution definition throughout the process hierarchy. This structure defines the closed circuit principle, which enables operational excellence by helping business stakeholders to adopt a process focused approach. This principle is key to improving the performance, while it decreases the time spent to close the cycle transforming the activity in real time.

In the current business environment, knowing how to deal with the dynamism of information is becoming a requirement as it offers opportunities for the company, but also threats because of uncertainties and turbulence in the global market, phenomenon attributed to globalization. To seize opportunities and guard agaisnt threats, companies need to develop decision support tools to make decisions more sensible and strategic, tactical and operational. [6]. In this context, it will be considered the closed circuit principle alongside the decrease of latency associated with the reuse and integration of resources that were not previously.

2.2. Recombinant Innovation

The term: recombinant innovation, which means, innovation based on the addition, dissociation and associantion of existing value propositions, using internal and external resources, instead of starting from the beginning [9]. Considering the problem and objective defined for this study, this resource that can and should be considered for the construction of a customized model of analysis and diagnosis of the production model and verification of nonconformities of a company in full activity and competition in the market.

Considering that innovation, the differential that every company seeks to help to excel in the market can be defined as “a discontinuous change and describes a new solution or renewal of an existing solution” [17]. The processes of innovation can be describe in different ways, such as radical innovation, improvement, incremental, ad hoc, recombinant and formalization [18]. In theory, “most innovations are based on recombination” [19], since “almost no innovation is entirely new” [9,20].

In this aspect, this study will consider the positive points in the process of Company Y, to apply the reuse and integration of resources that were previously not connected, rather than designing from the beginning for a rapid and efficient migration to the model of analysis and diagnosis of the production process to be developed.

3. Field Research

Field research was carried out in the production line for observation, collection, analysis and iteration of facts and phenomena observed in the approaches carried out on the company’s factory floor. A script was used with the activities carried out in the sector and its managers and the information standardized and documented by the company. The positive and negative points found during visitis to the company sectors ar shown in Table 2.

Table 2. Field survey result.

Sector	Positive points	Negative points
Assembly of product and by-product	Cell operators organize production as they see fit, within the set deadline and goal. Follow-up of the aid chain drive indexes, OEE (Global Equipment Efficiency) for calculating cell efficiency, GBO (Operator Balancing Chart) and Takt. According to the indications of the indices can be realized: Masp (Method of Analysis and Problem Solving) and Kaisen.	The same information is presented in two different ways and in two different locations, both in the system and in the frames, with manual updates and often outdated in a few hours. The system update is not real-time. Only three materials are traceable during the production process.
Mounting of transformer	The preparation, separation and supply for assembly is carried out the previous day with the schedule sent by the Planning and control of production.	Problems with copper wire defective and not traceable during the production process, causing delay. The steps of the process are totally handmade, with control only at the end of the process. Problem with the brittle spool especially in the coldest times of the year.

Sector	Positive points	Negative points
Expedition	An inventory is carried out weekly to check stock entry and exit for wrong data adjustments.	Annotations are made manually in frames to be passed to the system later - it is not a real-time update. Tracking and logging is a times consuming process and is not automated. The system usually duplicates the system bug (IT has already been reported). There is no checklist or alert for overdue tasks.
Final tests	When it fails, it goes to the repair cell. There is a report to visualize the production defects.	Partial traceability of the product is possible only when defective enters the history on the finished product label. All communication is by phone, email and daily meetings - none of the communications happen in real time.
Assembly of plates	All boards are inspected and when necessary, adjustment is done - this entire process is recorded and traceable. There is an hour to hour hour with production goals There is a study for the reduction of setup time and for the exchange of older machines.	The solder paste has lead, but for this material to be changed, older machines will need to be replaced. The notes on the progress of the production are done in frame, manually and the system is not updated in real time.
Warehouse	There is a study to evaluate the material conference time. There is another study for weighing the copper wire rolls that differed from the information in the purchase orders. Each material has a fixed location in the inventory to be saved, a location map. All externally mounted boards are tested when received. An inventory is conducted weekly.	The update in the system does not happen in real time, being inserted manually both in the system and in frames in the sector when it is possible, in the interval between the activities with priority. There is a trace available only to where the material is stored. All communication is by phone, email and daily meetings - none of the communications happen in real time, except for a radio deployed shortly for testing. The system is very bureaucratic when something happens that could be solved in a more practical way.

4. Diagnosis of the production model

With the field research and survey of the positive and negative points, a diagnostic strutucture of the production model was developed to determine the strategy to be adopted to comply with the objectives and guidelines that govern the company’s philosophy. The diagnostic structure helped in the description of the company's activities, production strategies, description of the advantages and possibilities for improvement of each sector and the enumeration of this information regarding the organizational structure, the administrative methods and processes and the product development, in addition to verifying the proximity or distance in relation to the achievement of the company's objectives, which led to the guidelines for putting into practice the theoretical issues raised during the development of this project.

Its objectives are related to cost-benefit and flexibility, however, to check proximity or distance in relation to the achievement of the company’s objectives, the objectives related directly or indirectly to the production process of the selected product were considered (table 3).

Table 3. Summary table of analysis of the diagnosis of the production process (source: the authors).

Diagnosis*	Selected Objectives							Type of change required
	Agility in service for spare parts	Vertical production chain in the manufacture of the main components of the product	Adaptation of line equipment to meet specific needs	Wide product line with variety of powers	Extensive own distribution capacity	Prompt delivery products	Lean philosophy ensures greater flexibility in processes	
System update does not happen in real time; the information is entered manually into the system during the intervals between activities; the information is repeated in tables manually and does not happen in real time; there is local and unconnected tracking in some departments; communication takes place by telephone, e-mail and daily meetings; emergency drives use radios; distribution routes have been optimized with wave distribution.	ap	at	0	at	at	ap	ap **	v2
The material used for welding does not yet follow RoHS guidelines; annotations are manual and made.	ap	at	ap	0	0	0	ap **	v3
Delay in the production process caused by a defect in the copper wire; copper wire coils are not traced, making it difficult to identify the supplier or purchase lot; process carried out with handmade tools; tests and updates at the end of the process; problem with brittle parts from some suppliers.	ap	at	ap	0	0	0	ap **	v3
The registration of production and updating of the system is done at the end of the process; registration is done manually.	ap	at	ap	0	0	0	ap **	v3
The data generated during the process are presented in two different ways, in two different places: in the system and in the information boards, manually and are not updated in real time. Three materials have traceability throughout the production process: plate, battery and transformer.	ap	at	ap	at	at	ap	ap **	v3
There is partial traceability of the product; only when the product is defective, a permanent record is created for traceability of the defect.	0	at	0	0	0	0	ap **	v2
Manual annotations on tables to then be passed to the system; no updates happen in real time; tracking and registration are not automated; there is no checklist or alert for overdue tasks.	ap	at	0	at	at	ap	ap **	v2

*synthesis of the diagnosis previously presented **the company folloes the Lean philosophy, however not all tools are being applied, characterizing the implementation process.

For the verification of proximity or distance in relation to the achievement of the selected objectives of the company by the sectors, a scale related to the level of compliance with the objective was used, where the variables were considered: (i) 0 = not applicable (null value); (ii) na = not answered; (iii) ap = partially attended; (iv) at = fully answered.

The scale previously described, led to the determination of guidelines for the type of change needed to put the theoretical issues raised into practice, classified based on the following variables with their application rules (correlated to meeting the objectives): (i) v1 = no change (rule: only at); (ii) v2 = weak positive change (rule: na + ap ≤ at); and (iii) v3 = considerable positive change (rule: na + ap > at).

Regarding the type of change, it is considered: v1 as no necessary change, as all objectives have been met; v2 as a weak necessary positive change, since in the relationship between the scale of meeting the objectives, most of them were met, that is, suggestions for improvements to be applied to the process will be made during the development of this project; v3 as a considerable necessary positive change, that is, points that must be considered for the design of the intelligent computational tool for diagnosis and analysis of product manufacture. The diagnosis of the production model presented aims to support the decisions to be made during the development of this project.

5. Analysis of Results

During the field survey it was verified that the stages of the production process are disconnected. In addition, decision making is based on snapshots that are often outdadet or inaccurate. The exchange of information between departaments, are avaliable in updated worksheets at the end of the day or in meetings at the beginning of the day. The techniques used to analyse operational data are isolated and without systematic linkage of criteria, that is, the updated information is not available in real time and is not connected and consequently making it impossible to have a holistic view of the whole production process. In relation to the traceability of information and materials, it is precarious and departamentalized, the information is not connected and lost at the end of each stage of the process, not being available to managers.

The diagnosis of the production model allowed to evaluate the type of change required in each sector of the company to guide the next steps of this project and to observe the gaps in the company's production process, directing the study towards the configuration of a model that represents the progress from the development of this project to the present moment, summarizing the main steps taken so far.

6. Conclusion and Future Steps

The research aims to identify the towards for a computational tool, with the goal is to improve the identification and analysis of nonconformities. Additionally, it is possible to identify opportunities to insert new technologies for product and process improvement alongside of the enterprise's production model. In this way, it was necessary to do an investigation in the management of all the processes of the company, in order to avoid the main problems that a research can face, such as the definition of the requirements for decision-making.

A complete mapping of all the existing activities of the production process was carried out. In addition to a diagnosis with assessment of the needs for changes in the process, which will be used as a reference by the computational tool during the implementation of the pilot system. In addition, recombinant innovation will be used to reuse and integrate resources that were not previously connected in the company and to deal with the dynamism of the business environment. The closed circuit principle aims to improve the performance of processes in relation to the time spent to close the cycle: connect, collect, analyze and act, controlling the activity in real time.

The next steps of this research include the selection of diagnostic tools and evaluation of the production process, definition of requirements and rules for decision making, analysis of project management platforms that are in accordance with the characteristics of the company to be carried out the migration for the new system without trauma for the company and the insertion of technology in the production process.

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Using AutomationML and Graph-Based Design Languages for Automatic Generation of Digital Twins of Cyber-Physical Systems

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Abstract. The interdisciplinary development of smart factories and cyber-physical systems CPS shows the weaknesses of classical development methods. For example, the communication of the interdisciplinary participants in the development process of CPS is difficult due to a lack of cross-domain language comprehension. At the same time, the functional complexity of the systems to be developed increases and they act operationally as independent CPSs. And it is not only the product that needs to be developed, but also the manufacturing processes are complex. The use of graph-based design languages offers a technical solution to these challenges. The UML-based structures offer a cross-domain language understanding for all those involved in the interdisciplinary development process. Simulations are required for the rapid and successful development of new products. Depending on the functional scope, graphical simulations of the production equipment are used to simulate the manufacturing processes as a digital factory or a virtual commissioning simulation. Due to the high number of functional changes during the development process, it makes sense to automatically generate the simulation modelling as digital twins of the products or means of production from the graph-based design languages. The paper describes how digital twins are automatically generated using AutomationML according to the Reference Architecture Model Industry 4.0 (RAMI 4.0) or the Industrial Internet Reference Architecture (IIRA).

Keywords. AutomationML, Graph-based Design Languages, Digital Twin, Cross-domain Engineering, RAMI 4.0

Introduction

Many products but especially production systems for the industry are mechatronic systems, which are developed by many people working together in interdisciplinary teams. The development process for those systems is nowadays seperated in different concerns, which are handled by the specialist departments such as mechanical, electrical and IT. The generated data however, are passed along the development steps from one department to another. Which leads to a high amount of intersections. The data, which the single departments receive along this process, is often converted in order to make it readable for the used engineering tools. Conversion of data always leads to a reduction

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of the original data and causes therefore extra effort in order to restore the missing information. The increasing digitalization of production systems and the associated increase in complexity, will most likely lead to aggravation. Especially the correlation between the IT department and the mechanical department ist critical for digital twins, because the dataformats that are used by commercial CAD software differs from the ones that are mainly used for graphical simulations.

To improve the situation a data format is needed which is capable of maintaining a unified digitalmaster model throughout the whole development process, that can be used by the IT tools off all specialiced departments without losing information that is required to build an accurate cyper physical system. One example of such a data format is AutomationML, which is currently developed by the Automation ML e.V. in cooperation with a large number of companies and universities. It is highly extensible due to its XML-based structure and therefore capable of saving the heterogeneous data, which is generated throughout the development process.

To deal with the rising complexity of production systems it is mandatory to increase the amount of simulation based functional validations. The current workflow for such validations is often based on manual labour, which is needed for the creation of the simulation models, and therefore prohibit fast iterations.

The approach presented in this paper incorporates a combination of the mentioned AutomationML standard along with an automated process of model generation by graph based design langues in order to overcome the limitations in the production process of cyber physical systems.

1. Relevant Work

1.1. Reference Architecture Model Industry 4.0

Industry 4.0 is in broad fields a very abstract concept, which is why the German Electrical and Electronic Manufacturers' Association (ZVEI) is developing the Reference Architecture Model Industry 4.0 (RAMI 4.0) in cooperation with various industrial companies.

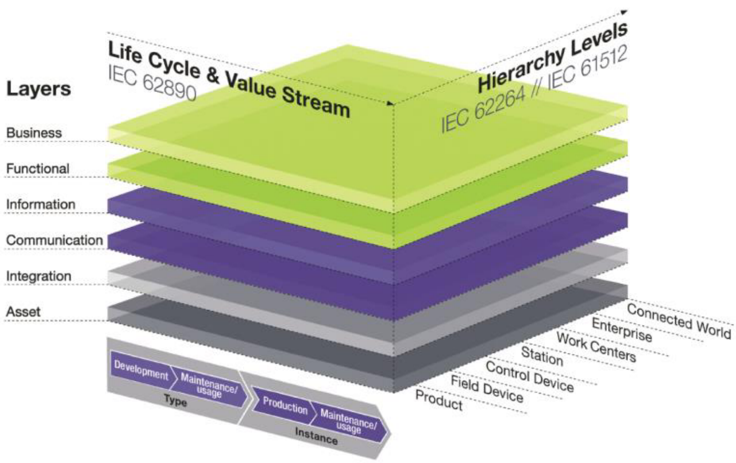

Figure 1. Layer model of RAMI4.0 [1].

1. *Layer model*
   The core of the reference model is a three-axis layer model, which is depicted in figure 1. It provides the possibility to represent any state of an arbitrary technical asset within the product life cycle.
2. *CP Classification*
   The CP Classification is intended to enable a simple classification of technical objects in the grid of the Reference Architecture Model Industry 4.0. The matrix of the CP classification shown in Figure 2. The x-axis shows the communication capability and the y-axis the recognition in the system.

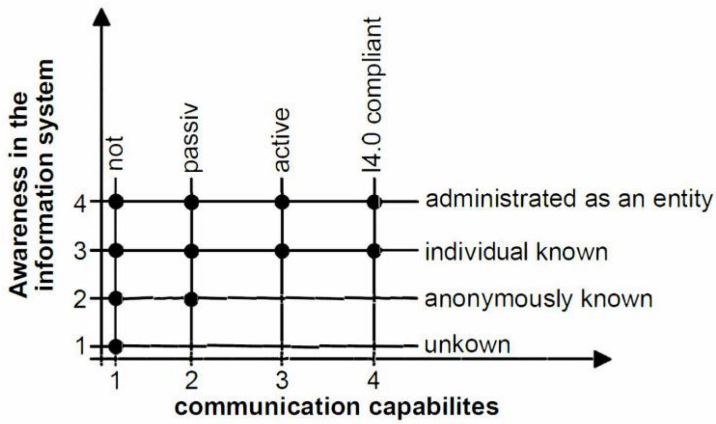

Figure 2. CP classification of RAMI4.0 (based on [1]).

3. *Asset Administration Shell*
   In order to depict a technical object in the digital world, the concept of administration shells introduced in the Reference Architecture Model Industry 4.0. The combination of administration shell and technical object referred to as Industry 4.0 component. According to the CP classification, which was already discussed earlier, industry 4.0 components therefore correspond to a CP classification of CP43 or CP44. In this paper, therefore, only elements of this characteristic are considered. The administration shell not only manages the data of the technical object but can also make its own functions available. These are made available as digital services in accordance with the reference architecture model. An example of such a service can be the execution of a diagnosis of the technical object by the corresponding administration shell. For example, statements about the remaining service life or the next service assignment are then calculated on the basis of the data collected.

1.2. AutomationML

Due to the rising complexity of Industry 4.0 based production systems, it is obligatory that engineering teams of different departments can exchange information efficiently. One format, which can handle heterogeneous data, is the XML based data format AutomationML (see e. g. [3], [4]]). It can contain much more information than for example a typical CAD exchange format like STEP or IGES. To make AutomationML easy accessible it incorporates several standards.

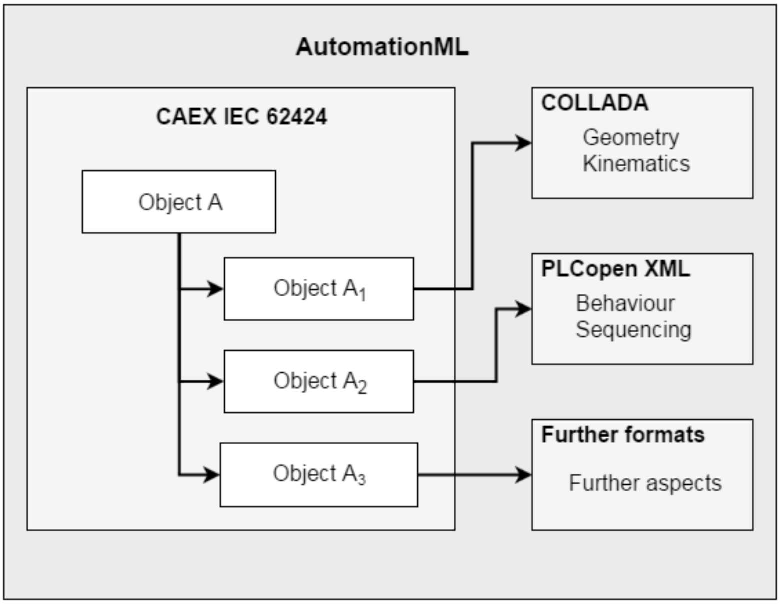

Figure 3. AutomationML Overview [2].

The open standards, which is used by AutomationML, are shown in Figure 3. The AutomationML file itself is based on the CAEX Format (IEC 62424) which is just slightly enriched. As it is XML-based and due to the possibility to reference other files, it is easy expandable. The present components, the hierarchical structure as well as the connection between the components are described with the CAEX Format. The COLLADA standard provides the functionality for the representation of geometry. It is capable of saving geometry as a boundary representation (typically for CAD software) as well as a triangulated mesh representation. Besides the geometry, COLLADA can also contain information about the kinematics and physics of an object, as well as other geometry related information. The PLCopen XML format is also included into AutomationML and makes it especially interesting for virtual commissioning purposes. Since it is based on the IEC61131-3, it adds the functionality to store and transfer programming languages for PLCs, embedded controls and industrial PCs. This data can be evaluated on software or hardware in the loop systems typically required for virtual commissioning. Also shown in Figure 3 is the ability to incorporate further formats to add special functionality to AutomationML.

2. AutomationML based Asset Administration Shells

An administration shell accompanies a technical object over the entire duration of the product life cycle. A wide variety of data is generated, in the design phase, for example, this is predominantly planning data such as 3D CAD data. As soon as the technical object is used as an instance, the type of additional data also changes, in this case measurement data, for example, as well as service and service life data is generated. In order to enable the persistent collection of this highly heterogeneous data, it is necessary to select a very flexible system or format for the asset administration shell.

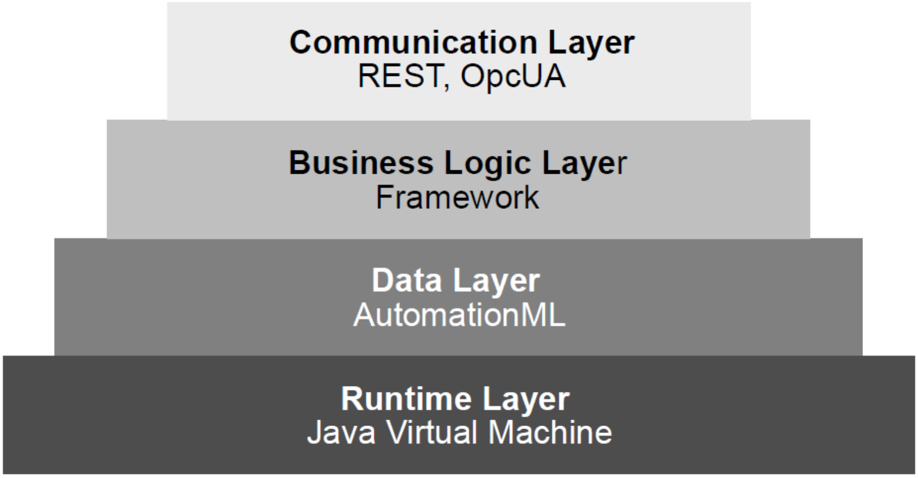

Figure 4. Implementation Layer Structure.

2.1. Implementation overview

The reference architecture model Industry 4.0 provides a basic overview of the objectives to be achieved with the model. For the majority of the components, however, no implementation recommendations can be derived. The authors therefore make some assumptions in the following, which serve as a basis for the later implementation.

- *runtime environment*
  The software-technical execution of the administration shells can be very varying. On the one hand, it is possible to centrally store the data and the runtime environment of the administration shells in a database-oriented system. Depending on the choice of the database, however, restrictions can arise with regard to the type and structure of the data. Another possibility is to embed the administration shells decentralized, for example directly on the managed technical object. As there are plausible use cases for both application scenarios, a possibility should be chosen that enables both scenarios equally.
- *data repository*
  As already mentioned in the runtime environment, data can be stored central or decentral. In particular, the choice of the data format in which the data is made available plays a central role. A proprietary data format can lead to integration problems with external systems, especially due to there large variance in the software products available. It is therefore advisable to choose an open standard in order not to restrict the use of an administration shell. The chosen data format must be able to contain the already mentioned heterogeneous data, which is generated during the product lifecycle.
- *Communication*
  The communication capability of an administration shell is elementary and should therefore receive special attention. In the reference architecture model,

the term ′service-oriented architecture′ is used at this point. Communication based on such an architecture has proven itself in various software projects in recent years and is therefore recommended here. However, the authors are of the opinion that a further communication option that is closer to the machine would facilitate the integration of the administration shells at the machine level. Therefore, two forms of communication are considered.

The resulting layer-like structure is shown in Figure 4. In this figure, the individual layers are already occupied with technologies that can fulfil the assumptions made. A fundamental consideration which has to be addressed with the selected programming language is the compatibility with different execution systems. Therefore, an approach was selected which allows the execution of the code on different platforms such as Windows or Linux environments. Thus, Java as programming language was selected, which allows due to the Java Virtual Machine to run the same code on different platforms.

2.2. Java AutomationML Framework

The framework provided by AutomationML e.V. is currently only available on the basis of the .NET Framework programming language C#. A use in Java is therefore not possible. For this reason, a Java-based AutomationML Framework is required for the approach described above, which allows the effective use of AutomationML under Java. Since this AutomationML framework is to be used in particular for the use in connection with the administration shells, some additional requirements have to be fulfilled.

- *Easy integration of additional service life data*
  The main task of the framework to be created is the integration of additional data that is generated during the product lifecycle. It should be possible to integrate any kind of additional data into the AutomationML file.
- *Complete serialization and deserialization*
  In order to make the data more robust against malfunctions and to reduce memory requirements, the data must be able to be both saved and loaded as AutomationML files (*.aml). This requires a serialization and deserialization mechanism.
- *Toolkit for mathematical operations based on the FrameAttributeType attributes*
  Positions and rotations of individual components can be stored in AutomationML as FrameAttributeType. This FrameAttributeType attribute contains the position and rotation of an element. The rotation is held in Euler angles, which is especially problematic for complex mathematical operations in 3D space. Therefore, two new classes are introduced for the arithmetic operations based on the FrameAttributeType attributes. The FramePosition element contains the position portion of the FrameAttributeType attribute. The FrameRotation element contains the rotation part of the FrameAttributeType attribute, which is converted into a quaternion FrameRotation. In order not to violate the rotation sequence defined by AutomationML e.V., an in 2006 founded industrial consortium, the conversion is performed as shown in equation 1.

$$q_x * q_y * q_z = q_{res} \quad (1)$$

The indices indicate the rotation around the individual axes. By converting the rotations into quaternions, the required arithmetic operations for spatial calculations are reduced and the mathematical problem of the "gimbal lock" (see also [8]) is avoided. Rotating a position p0 by a given quaternion qn can then be expressed in the following way.

$$p_1 = q_n * p_0 \qquad (2)$$

This system makes it easy to perform complex mathematical operations based on the FrameAttribute type.

- *Integrated Toolkit for creating and modifying PlcOpenXML data*
  In order to enable an administration shell and thus also the managed technical object to react adaptively to changed boundary conditions, it may be necessary to adapt the PLC program used. The open standard PlcOpenXML is integrated in the AutomationML standard for the purpose of managing PLC programs. In order to simplify the modification of these programs, a toolkit is implemented which enables the semantically and syntactically correct modification of PlcOpenXML data.

2.3. Asset Administration Shell Framework

As shown in Figure 4, the administration shell framework is located between the communication layer and the data layer and represents the actual business logic. The mapping of the data to the communication is basically possible in two different forms:

1. Division of an AutomationML structure into individual data elements
2. Mapping of the complete AutomationML structure as a single data element

The first is particularly suitable for communication forms that require such a granular division, e. g. machine controls. Usually this is necessary for runtime-variable data. Variant 2 is e. g. suitable for planning data which should be imported into a software and extended if necessary.

2.3.1. Machine to Machine Communication

One aspect of industry 4.0 is the relocation of intelligence by embedding control units into subassemblies to form independent objects. This increases the need of a standardized machine to machine communication. Therefore, the Asset Administration Shell has to be able to communicate in this standardized way. In the recent past the OPC UA standard proves itself as valid competitor for future standardized machine to machine communication. Thus, this standard was implemented in the Smart Asset Administration Shell Framework.

2.3.2. Human-Machine-Communication

As even in highly automated processes the influence of an operator is necessary, the Human-Machine-Communication has to be in a comparable quality as the machine to machine communication. To provide a Human-Machine-Communication there are several options available. One typical option nowadays is to embed a display within the technical system, e. g. the control panel at a tooling machine. As this is probably the best option for machines with one single control unit, it can hardly be applied to machines which consist of dozens of control units. Therefore, the Human-Machine-Communication is realized comparably to a service orientated architecture, to enable a user to easily interact with arbitrary control units or Asset Administration Shells.

3. Conclusion And Further Research

The acceptance of industry 4.0 components and the reference architecture model industry 4.0 will depend strongly on whether the manufacturers of the systems find a common data technology basis. The combination of AutomationML and the reference architecture model industry 4.0 could represent such a data technical basis and thus contribute to the improved interoperability of these systems. These models can automatically be generated through a production pipeline based on graph-based design languages as described by Kiesel et al. [5] and Beisheim et al. [6], which allows a higher number of simulations for functional validation. In order to confirm this assumption, however, further research is necessary in the future.

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A Preliminary Discussion of the ACATECH 4.0 and AHP to Measure Enterprise Maturity Level Index

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Abstract. Many organizations have redesigned their measurement systems to ensure that they reflect their current environment and strategies. Thus, it is extremely important that the responsible manager knows all the strengths and weaknesses of his organization, having all the maturity axes mapped, highlighting his strengths and weaknesses, to anticipate problems, becoming a company with greater potential competitiveness, because the failure is not to ignore the problem, but to ignore it. Given this, when measuring the Maturity Level Index, you can get an overview of the organization, becoming a radar to know the strengths and weaknesses, thus providing a basis for formulating a decision making and strategy to implement actions to improve performance and organizational maturity. The Acatech Industrie 4.0 (AI4MI) + AHP maturity index has the principle of providing companies with a guide for this transformation, based on the assessment of weaknesses or disagreements with the objective in the action plans, thus obtaining a continuous improvement in the evaluated stages, generating knowledge from the data, to transform the company into an agile organization, with quick decision making and adaptation in multiple business scenarios and different areas of the company. This article presents a preliminary discussion on the benefits of this proposed model for analyzing the measurement of the ACATECH + AHP Maturity Level Index, as to its advantages, results, added value.

Keywords. Maturity Index, Industry 4.0, Road Map, Decision Support, Performance Measurements, Operations Strategy.

Introduction

Currently, what governs the rules of competitiveness and survival of a company are: technological innovation, creativity, quality, low cost, customer satisfaction. And correlating all these factors is not an easy task. In recent times, much has been said about Industry 4.0 and its benefits and impacts on industry and society. The 4th Industrial Revolution brings us topics such as the Internet of Things (IoT), digitalization, intelligent and independent processes, big data, cloud storage, and many other macro themes [1]. The fact is that all this transformation causes curiosity, but also fears about culture, the way of thinking, and new ways of manufacturing. Industry 4.0 is not only about

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connectivity between machines, processes, and products, but also about growth and organizational development in general [2].

The use of new technologies and the implementation of new knowledge through new information processing metrics inevitably brings us new ways of working, new jobs with which we need professional knowledge and experience [3]. Therefore, the first challenge and task to be carried out before any implementation tool presented by Industry 4.0 is to prepare the environment and culture of the whole society that will be directly and indirectly involved with this type of industrial revolution, thus designing a strategy for implementation aligned with your business strategy [1; 4].

The concern with meeting the client's personalization requirements at the desired level of quality, competitive selling price, low manufacturing cost and profitability to remain competitive in the market is a complex and exhausting task [5]. For its implementation, a previous study must be carried out to map the environment to be modified, type of product, mission, and vision of the company and, thus, be able to be more assertive when performing the step by step for the application of maturity index measurement. Companies will only be able to enjoy the benefits of applying this tool if they implement the steps correctly and respecting all their stages in the process.

Performance management is a key factor in identifying skill gaps in any area of an organization or individual. Thus, it is of great importance to link the company's goals, even employees, to the company's Industry 4.0 strategy, [1]. The question is which is the best method, and how to interpret the results obtained.

This article will be structured as follows: Session 2 is dedicated to the problem statement; Section 3 presents the background, example work to promote the discussion and presents the highlighted model; Session 4 deals with the preliminary discussion between the advantages and disadvantages on the presented methods and, finally, session 5 presents the conclusion.

1. Problem Statement

Competitiveness in the market, customer requirements, rapid adaptation to changes, connectivity, and digitalization of data bring us to the reality of change. The question is: are our factories ready to receive this transformation? What is the impact of measurement systems on the organization's competitiveness and strategy? What method to measure maturity index can organizations use to ensure that their systems evolve, contributing to the increase in maturity? The fact is that many managers see the need for change, both physical and cultural, but it is difficult to measure the distance between the current state of reality and the desired state to be achieved. For such questions to be answered, it is necessary to know the level of maturity existing in the organization, and for that it must be clearly known which method to use, and most importantly, correctly interpret the extracted data so that action plans and strategies can be executed. However, knowing how to apply and interpret the best method is not a simple action.

2. Contextualization

Industry 4.0 brought with it facilities, autonomy, connectivity, integration between the real world and the virtual. But all these advantages are not available so soon, it is necessary to promote adaptations throughout the organization. This implementation is a highly complex transformation, which does not occur quickly, requiring analysis, modifications, investments not only in strategic and technological aspects, but also in social aspects.

ACATECH + AHP assists, from the company's business strategy, identifying strengths and weaknesses in various perimeters, assisting in the formation of simulated scenarios according to the result obtained, through the functional areas of Development, Production, Logistics, Services, Marketing and sales. Each functional area of this is classified into four sub-levels: Culture, Organizational Structure, Resources, and Information Systems. Each sub-level is classified into 6 classes that refer to the requirements of the implementation phases of the Industry 4.0 stages [6], namely: Adaptability, Predictive Capacity, Digitization, Computerization, Transparency, Visibility (Figure 1).

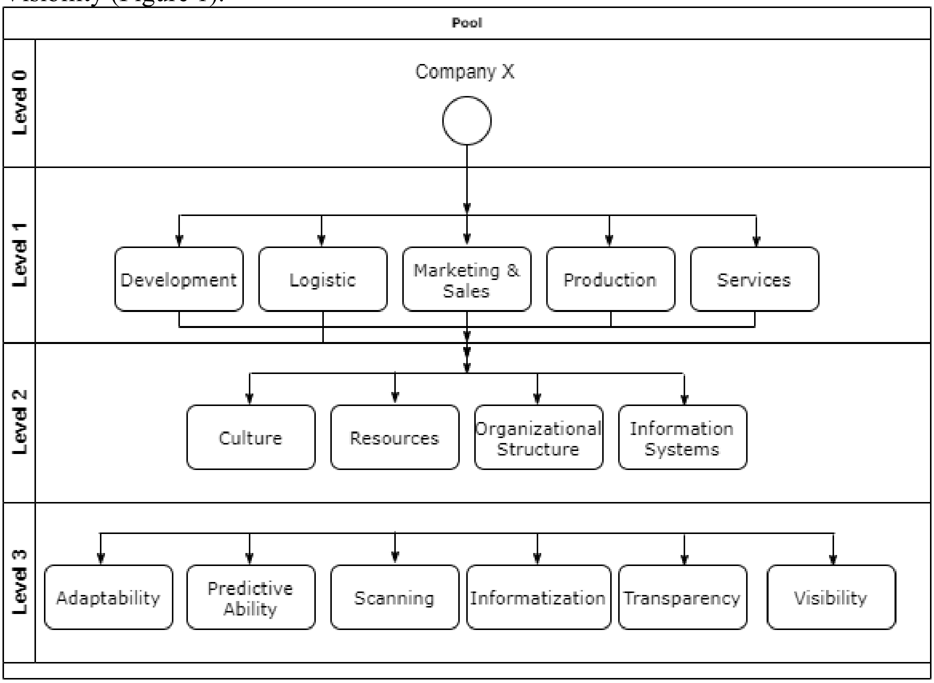

Figure 1. Structure ACATECH, from adapted [6].

This methodology occurs through the elaboration of a questionnaire (script), mapping the questions in all axes so that all levels and sub-levels are included, where people linked to the company and from different areas can answer, thus ensuring that they do not there is a trend or influence on the result, consequently contributing to the mapping and increased maturity [6].

The proposed structure is described in Figure 2, which after compiling the responses to the applied form, the next phase is to encompass the AHP. The hierarchical structure is assembled in AHP, allowing that through the responses interpreted by the ACATECH form, the comparisons created by the AHP are filled out. Based on the result obtained, it is possible to simulate scenarios, prioritizing other pillars (Adaptability, Predictive Capacity, Digitization, Computerization, Transparency, Visibility), being able to analyze the impact of changes and future strategies, thus helping decision making.

As mentioned, the ACATECH + AHP structure, proposed by [7], which is a synergy between the ACATECH method and the MCDM, AHP model, brings great detail when interpreting the result provided by the application of the structure

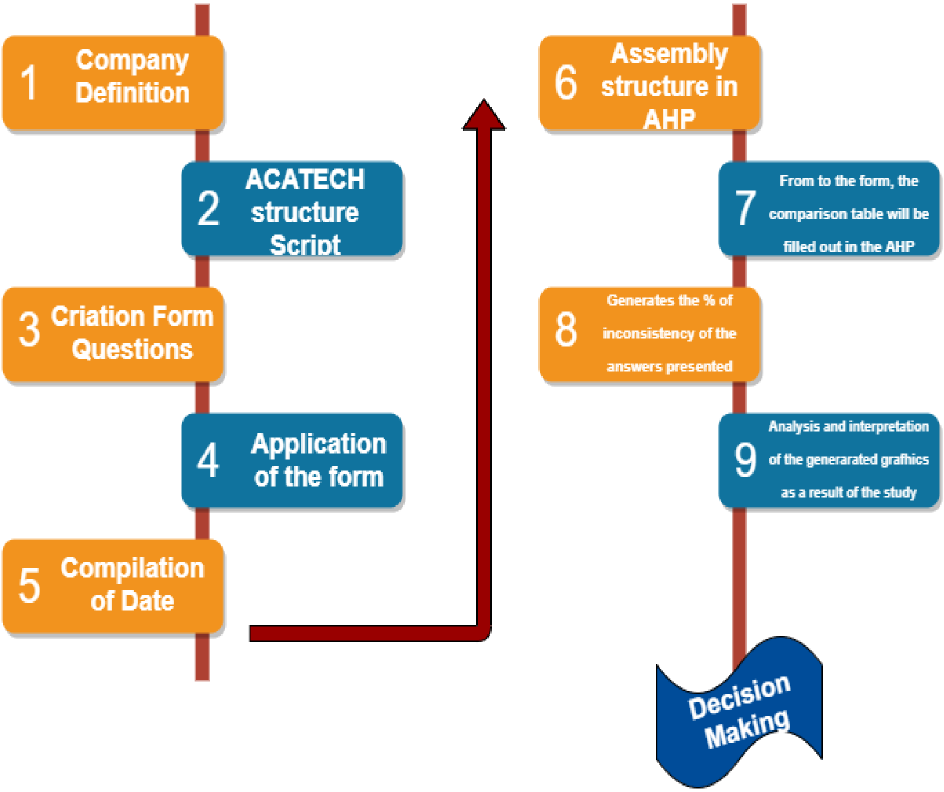

Figure 2. ACATECH + AHP Method Steps, adapted from [7].

3. Preliminary Discussion

In [1] the AI4MI framework is applied in a mining company called Master Drilling. Its goal is to be the first point of contact for any customer who wants to expand their current mining operations or start new mining operations. Thus, the objective focuses on how maturity indexing is used to identify the strengths and weaknesses of Master Drilling. The authors needed to change the ACATECH structure to suit the company's reality, together with a readiness measurement model, commissioned by the IMPULS Foundation of the German Engineering Federation.

In [8], the authors applied the AI4MI framework in 3 cases of several large Danish manufacturing industrial companies, intending to obtain an understanding of how the company is in the relation of the requirements of Industry 4.0, to assess their digital maturity and to guide the definition of a script to address the digital transformation in the companies in question, suggesting improvement activities according to the obtained result. The authors pointed out the need, after application, for a large team of experts to carry out the evaluation process, especially to translate the data collected and mapped into recommendations for improvement, also pointing out the difficulty in interpreting the result provided by ACATECH.

In addition to the difficulty of interpretation, we find it difficult to find work applying ACATECH, or this factor may be correlated with its complexity in interpreting the results.

Thus, we can see that other authors also encountered limitations during the application and when interpreting the results, having the need to adapt the model associated with another one or to outsource the interpretation to a more technical group.

In the same way as the authors mentioned above, the author [7] commented on the challenges, limitations found during the application of the ACATECH tool, which motivated to associate decision-making with an aid method, in a way to interpret and instruct the analyst as to the result obtained, which occurs through statistical, graphical interpretations, simulating scenarios (Figure 3), more playfully and intuitively, when compared to the product supplied to ACATECH, a radar graph. However, when analyzing the ACATECH + AHP model, which proved to be very advantageous, the limitation due to the extension of the method was observed, becoming tiring, and also during the completion of the AHP strike, it can generate confusion.

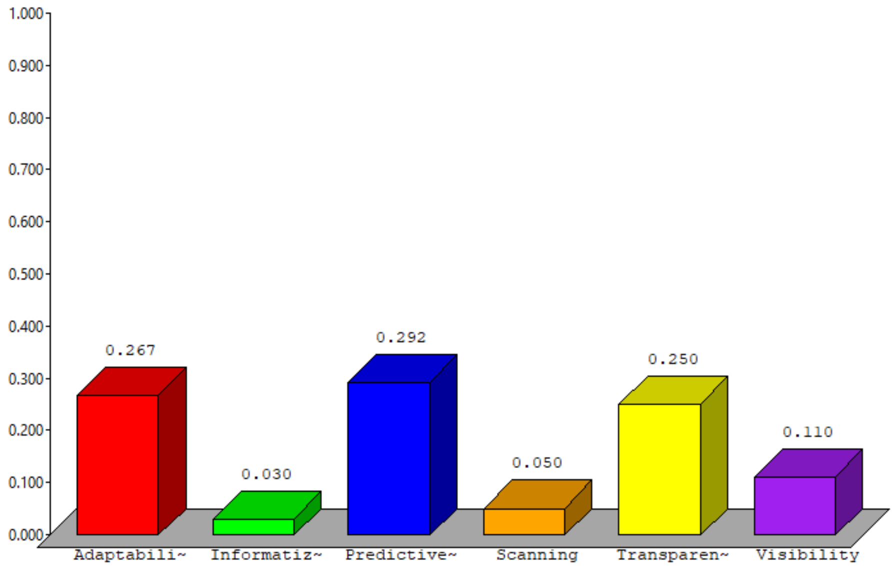

Figure 3. ACATECH + AHP Method Steps, taken from [7].

Figure 3 reveals how the ACATECH + AHP structure presents the interpretation of the maturity index measurement result.

After performance measurement, actions must be established to optimize the points to be developed or the points that impact according to the established strategy.

Figure 4 provides the following explanation: Organizations must inform/implement their existing strategy, linking it as data entry, with the technological developments that Industry 4.0 makes available (IoT, Big Data, Cloud). Another entry, which is on the rise, is industries or the processing of products or services linked to sustainability, not just products scheduled to be reused or recyclable, with return, but more mature and sustainable.

Thus, the organizational strategy must reflect three new dimensions, namely, the creative use of technology, unlocking innovation through collaboration and co-creation, as well as a sustainability agenda to create a competitive advantage. In this way, the organization would implement its strategy using a performance measurement framework, with behavior and measurement in a social environment. Finally, organizations must manage their performance not only by measuring internally, but also in collaborative networks and social media and, in some way, by measuring social factors, requirements, customer, and competitor acceptability. The result of this stage is the evolution of collaborative networks and social evolution [9].

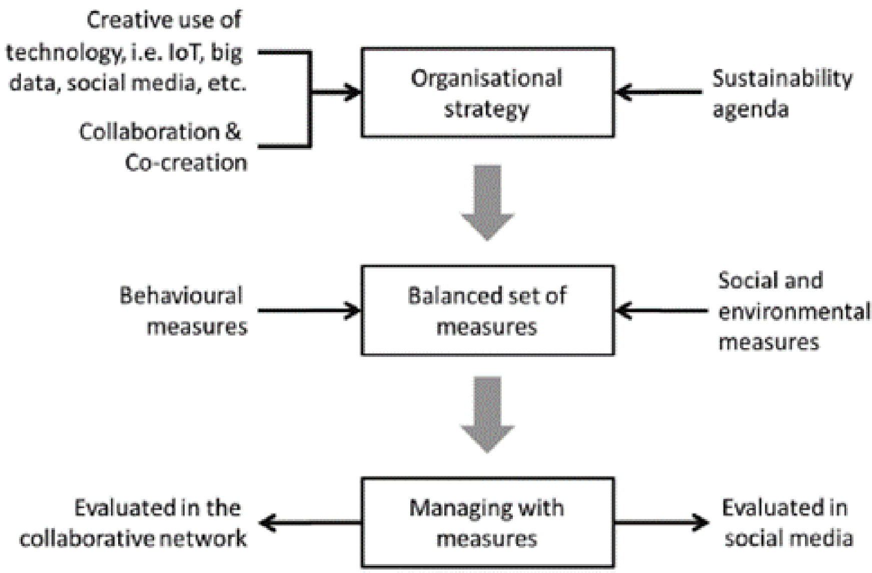

Figure 4. ACATECH + AHP Method Steps, taken from [1].

4. Conclusion

Through this article, we were able to demonstrate and complete the displayed model ACATECH + AHP, when compared with the ACATECH structure itself and other methods formed from it, shown to be very efficient, practical, effective and quick to assess the maturity index. The main conclusion is that ACATECH is a great tool, but in all cases analyzed, it shows confusion in the relationship with the interpretation of the result, being necessary, as reported in the mentioned article, an outsourcing of the interpretation of the results, so that the measures and action plans are taken correctly.

Research shows that resources widely grouped into the categories of processes, people, systems, and culture allow the organization to deal with the changing environment and modify its performance system according to its changes and evolution.

For performance to effectively contribute to the management of the organization in question, it is necessary to provide feedback loops on the measures, that is, periodically monitor their evolution, problems, and success. This leads to the recognition of various types of performance measures, especially for long-term business improvement initiatives.

It is worth mentioning that old performance measures must be excluded after the evolved system, so that they give space to measures that reflect the reality of the scenario and the current need.

As next work, implement the ACATECH + AHP structure in cases of companies with operations in different markets, not only to measure maturity in different segments, but mainly to measure the difficulty of implementing in several sequences, as well as correlating the strengths and between companies and between companies in similar markets.

Acknowledgment

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Systematic Literature Review on the Use of the Internet of Things in Industrial Logistics

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Abstract. In the globalized economic scenario, the ability to adapt to the flexibility of demand is crucial for the longevity of companies. In this context, industrial logistics has a key function in production flexibility. To meet this urging need, the concept of industry 4.0 brings along the use of IoT (Internet of things). Considering the importance of industrial logistics on the flexibilization of production lines, this present research presents a systematic literature review through the application of the PROKNOW-C method (Knowledge Development Process – Constructivist) aiming to understand the use of IoT (Internet of Things) in industrial logistics. The findings can be summarized by four strategical elements that should be leveraged in the decision making process by any company willing to implement IoT in industrial logistics as key factors for implementation success: clear process definition, implementation planning, people training and standardization.

Keywords: industrial logistics, Internet of Things.

Introduction

Through the capability of flexibilizing productive processes, companies are able to rapidly meet variability of customers needs (Mukherjee, 2017). This demands that processes produce different product lines on the same physical structure composed of machines and equipments (Pine II and Victor, 1993). Thus, to make sure flexibility is achieved (Mukherjee, 2017) on production lines, industrial logistics plays a major role, rapidly adapting to mix and products changes and reorganizing internal flows of material and information aiming to supply various raw materials and components needed for products or services, when they are requested, in the right quantity, in the right place and under the lowest possible cost (Cooper, Lambert, and Pagh, 1997).

Inside the context of manufacturing, there are several logistics actitivities being executed to guarantee the feeding of raw material to allow productive processes to run smoothly. (Ellinger, 2000; Hofmann and Rüsch, 2017). After the industrial revolution and following the rise of the Toyota Production System (Ito, 2016; Kidd and Monden, 1995; Liker and Morgan, 2006; Spear and Bowen, 1999), logistics became a study subject and was therefore subdivided in three main areas:

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- **inbound logistics:** loading and transportation of raw materials and componentes from suppliers to customers, factories and/or receiving/unloading locations;
- **industrial logistics:** material handling from its receiving in the unloading locations to and throught the manufacturing processes where the material will be transformed in finished goods; and
- **outbound logistics:** loading/collection of finisehd goods in units or batches from the manufacturers and deliveries of such to the customers location/drop points.

It is possible to find several articles that addresses the usage of Internet of Things in logistics. In order to better understand the specifics of the available technology and the applications in logistics, it is necessary to organize the papers and analyze them in the general context of use and need.

This research presents a systematic literature review through the application of the PROKNOW-C method (Ensslin et al., 2010), aiming to understand the use of the Internet of Things in industrial logistics. In particular, the literature review aims at clarifying the strategical elements and implementation factors that should be leveraged in the decision-making process by any company willing to implement IoT in the industrial logistics. Thus, Section 1 presents the selection of the bibliographic portfolio, Section 2 the bibliometric analysis of selected works, and Section 3 the content analysis of these works. Section 4 draws conclusions and makes remarks related to future works.

1. Selection of the bibliographic portfolio

The selection process of the article portfolio consists primarily of the selection of publications that are considered relevant in the area of knowledge to the desired research topic and fully aligned with the researcher's perception. This includes the raw bibliographic portfolio and the filtering of this raw portfolio for the selection of the articles that will compose the bibliographic portfolio to be analyzed.

1.1. Raw bibliographic portfolio formation

For the formation of the raw bibliographic portfolio, search terms and search period need to be defined, as well as the reference databases in which works will be searched for with these search terms.

Table 1 illustrates the search terms used, divided in two axes, one with terms related to logistics and the other with terms related to the Internet of Things. It must be highlighted that the process of establishing these search terms involved first scoping a set of terms and, through an iterative process of searching in some of the selected reference databases, refining them according to the quality of results that were obtained.

Table 1. Search axes and keywords.

Axle 1: Logistics	Axle 2: Internet of Things
Logistics	Internet Of Things
Industrial Logistics	IoT
Logistics Sensors	Industrial IoT
Logistics Devices	

After the definition of the search terms and the scoping of some scientific reference databases, three of them were selected to search for articles to compose the bibliographic portfolio, namely: Scopus, ScienceDirect and Web of Science. The searching process occurred between September 20th and October 2nd, 2019 with a date filter for articles published between the years 2014 to 2019 as the search period. This resulted in a raw total of 914 works related to the research topic. Search results related to each one of the search terms are shown in Table 2:

Table 2. Search results by keyword combination.

Keyword	Number of articles
IoT	33.520
Internet Of Things	11.020
Industrial IoT	3.571
Internet Of Things & Industrial IoT	2.542
Logistics Sensors	2.265
Logistics & Internet of Things	**914**

Finaly, an adherence test was used to check whether the keywords initially determined for searching for publications in the scientific reference databases are the ones that best align with the research theme. The Proknow-C method (Ensslin et al., 2010) suggests that a random sample of two publications be selected from the portfolio among the 914 articles that make up the raw article bank. The presented test result showed a good alignment.

1.2. Bibliographic portfolio filtering

After conductin the searches in the reference databases, articles need to be selected based on their affinity to the research theme (use of IoT in industrial logistics) and relevance in the research community. This filtering process includes:

a) **Repeated articles filter:** of the 914 articles, 172 were duplicated, resulting in 742 unique works.
b) **Title filter aligned with the research theme:** titles of the works were read to see if the aligned with the research theme. Only 104 papers out of the 742 unique works were aligned.
c) **Abstracts filter aligned with the research theme:** in this step, all 104 articles had their abstracts read in full, and only 35 were selected for being aligned with the research theme.

d) **Scientific recognition filter:** the number of citation of the selected papers in Scopus was used as criteria. Only 23 articles were selected for having at least 5 citations (selected baseline) or fewer than 5 citations but published within the last 4 years in a journal with Journal Citation Ranking (JCR) above 1.5.

e) **Integral content alignment filter:** in this stage, 5 articles were excluded due to misalignment with the research theme, leaving 18 articles to be used in this study. These articles are listed in Table 3.

Table 3. Articles selected to constitute the bibliographic portfolio.

#	Author	Articles title	Year	JCR	Citations
1	Pawel Tadejko	Applicaton of internet of things in logistics current challenges	2015	0.505	16
2	T Stock, G Seliger	Oppotunities of sustainable manufaturing in industry 4.0	2016	2.571	428
3	Zhang, Y Guo, Z and Liu, Y	A framework for smart production-logistics systems based on CPS and industrial IoT	2018	0.174	27
4	Martin Wollschalaeger, Thilo Sauter and Jurgen Jasperneite	The future of industrial communication	2017	0.174	408
5	Christian Prasse, Andreas Nettstraeter and Michael tem Hompel	How iot will change the design and operation of logistics systems	2014	0.174	21
6	Ethan Yun Yao Chen	A new approach to integrate internet of things and software as a service model for logistics systems: a case study	2014	0.124	51
7	Mengru Tu	An exploratiry study on internet of things in logistics and suppluy chain management	2017	0.308	22
8	Chunling Sun	Internet of things leads wisdom logistics	2018	1.946	0
9	Judti Nagy Judit Olah, Edina Erdei, Dominican Mate and Jozsef Popp	The role and impact of industry 4.0 and the internet of things on the business strategy of the value chain - the case of hungary	2018	0.124	41
10	Sasa Aksentujevic, David Krnjak, Edvard Tija	Logistics environment awareness system prototype based on modular internet of things platform	2015	0.458	254
	Christian Poss, Thomar Irrenhausers, Marco Pruelgmeier	Perceptionbased intelligent materialhandling in industrial logistics environment	2019	3.033	10
12	Diogenes Marcelo Cassiano Coriguazi, Alexandre Tadeu Simon, Maria Rita Pontes Assumpção	Modelo de gestão da tecnologia e do conhecimento para a integração de sistemas fisico-cibernéticos (CPS) aos processos logísticos das empresas	2017	0.447	12
13	Mengru Tu, Ming K Lim, Ming-fang Yang	IoT-based production logistics and supply chain system- part 1: modeling Iot-based manufacturing supply chain	2018	0.308	10
14	Jian Liu, Shengsheg li and Yunlei Zhou	Research on the dymamic relationship between industrial structure adjustment and the development level of modern longistics industry	2018	0.558	51
15	Andrei Bautu, Elena Bautu	Quality control in logistics activites through internet of things technology	2016	3.198	0
16	Behzad Esmaeilian, Sara Behdad, Bem Wang	The evolution and future of manufacturing: a review	2016	2.571	282
17	Lucas Santos Dalenogare, Guilherm Brittes Benitez, Nestor Fabian Ayala	The expected contribution of industry 4.0 techonologies for industrial performance	2018	2.571	60
18	Somayya Madakam R. Ramaswamay, Siddharth Tripathi	Internet of things (IoT): a literature review	2015	1.446	498

2. Bilbiometric Analysis

With the selection of the bibliographic portolio concluded, the set of 18 selected articles was quantitatively analyzed according to the procedures presented by Azevedo et al. (2014), de Oliveira et al. (2016) and Waiczyk and Ensslin (2013). Two representations are shown here, the estimation of the degree of relevance of journals and the estimation of the scientific recognition of articles.

2.1. Estimation of the degree of relevance of journals

All journals in which the selected articles were published were searched for their amount of citations in the Journal Citations Report (JCR). This is shown in Figure 1. The highest scoring journal was the Journal of Manufacturing Systems, as shown in Graph 1, with 710 citations:

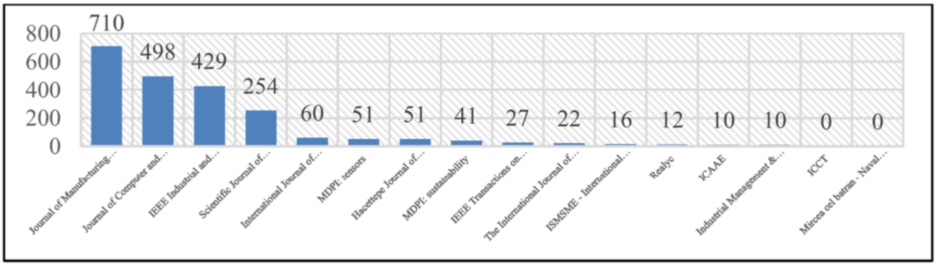

Figure 1. Index of journals in the JCR, Source: Web of Science.

2.2. Estimatio of scientific recognition of articles

The scientific recognition of articles consists of researching for the number of times the article was cited (Figure 2). The Scopus platform was used as a basis. The article with the most citations was: "Internet of Things (IoT) a literature review", with 498 citations. It is possible to notice that recent publications may have a lower number of citations, but still they present a high relevance to the research theme, according to what was previously discussed.

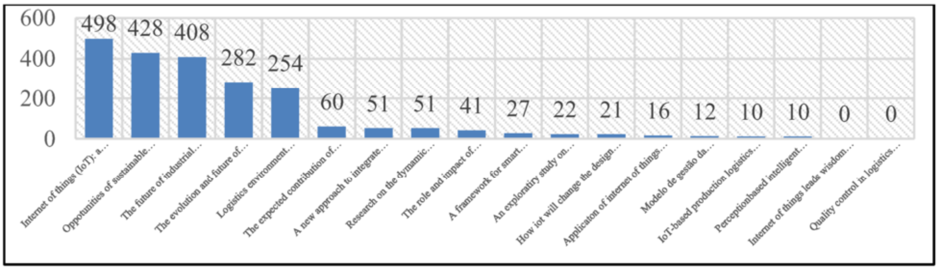

Figure 2. Number of citations received by the selected articles, Source: Scopus.

3. Content analysis

The objective of this section is to provide a conceptual basis built on the knowledge acquired from reading the articles of the bibliographic portfolio.

Wollschlaeger et al. (2017) present a review of technological trends and their impact on industrial communications. The authors state that sustainability of a company's competitive advantage lies in being able to adapt quickly to the variation in demand and, in this framework, all decisions must be deployed to the level of activities, both in industrial logistics and in production. These decisions happen simultaneously all the time, leading to the principle of optimizing processes and products. Still according to the authors, there are two topics that need to be considered for the successful implementation of cyber physical systems (CPS) such as IoT-based logistic systems:

a) **Intelligence modeling layers:** CPS deployment must be done at the activity level to ensure that the change in orders coming from the customer permeates the initial activity, avoiding an opposite effect, which, as a consequence, can generate large inventories throughout the manufacturing structure and between processes.
b) **Intelligent auto configuration of services:** when implementing a CPS, it is necessary to ensure that all internal logistics services and activities are fully adaptable and reprogrammable.

Li et al. (2018) corroborates these points by stating that the evolution of the industry is only achieved with a good level of development of the communication interfaces between the manufacturing processes and the logistical systems.

In the work of Tadejko (2015) a review of the concept of IoT is made, discussing its emergence and evolution until the moment in which we live, and the changes and improvements that are perceived over the years. The author also comments that for a complete and wide diffusion of the concept and application of IoT in the most diverse segments, many years will be necessary, but the speed of expansion in recent years is impressively greater than in the last decades, all this promoted by the cheapening of sensors and connection technologies. The greatest concern presented by the author is the information security in using these devices. Among the benefits presented by the authors of using IoT in logistics are:

a) **Flexibility:** provide local intelligence to the decision point. According to the author, flexibility can be translated as interchangeability at the physical level (machines and equipment). This concept of interchangeability is directly linked to the concept of, when receiving an order change, having the ability and autonomy to quickly adapt, change functionality, execute new solutions or supply different products. It also points out that at the operational level, this type of application can foster changes in the level of perceived performance and the unit flow (One Piece Flow) will be allowed and promoted.
b) **Robustness:** the author defines robustness as intensity against interruption and operational errors. The time between failure and recovery makes it possible to measure the robustness of the process. In this way it is suggested that MTBF i (Mean time between failures) is monitored, to show the time between the detected failure and the recovery of operations.

In the view of Mayer and Schneegass (2017), the application of IoT in industrial logistics can be described as an evolution from "monitoring" the material flow to "self-controlling" this flow, obtained by autonomous behaviors by logistic objects within the supply chain.

In the work of Chen et al. (2014) there are examples of improvements in logistics processes with the use of IoT, such as:

a) The replacement of labels with bar codes by RFID sensors (Radio Frequency Identification) would allow a process of receiving materials and dispatching them much faster (Want, 2006).
b) The use of reusable container with GPS (Global Positioning System) locks (Xu, 2007), highlighting the advantage of monitoring loads 24 hours a day and the benefit of reducing environmental impact, due to reuse.
c) The use of GPS locators (Aughey, 2011) allows real-time monitoring of the material flow and packaging and material inventory, both within the factory, in transit and in the possession of suppliers or customers.

4. Conclusions

Using the Proknow-C method (Afonso et al. 2012; L. Ensslin et al. 2010; Linhares et al. 2019; Vilela, 2014; Isasi et al., 2015) it was possible to identify a solid base of works closely aligned with the research theme.). The use of the method is highly recommended to obtain a useful knowledge base that will permeate the future works and will foster academic and industrial development.

As an overview of the use of IoT in industrial logistics, based on the knowledge acquired from the reviewed material, it can be said that the success of a digital transformation is directly related to four main factors:

a) **Clear process definition:** digital transformation is only recommended after the maturation of current industrial logistics processes, since investment in not well defined processes can create operational barriers that, instead of benefits, will become operational difficulties, negatively impacting the performance of logistic processes, which must be seen as services to customers (internal and external), and consequently, the results of the industry. According to Mayer and Schneegass (2017) the robustness of a cyber-physical logistics system (CPLS) is mandatory and can be defined as the insensitivity to interruptions and errors during the operation, that is, a failure-proof process.
b) **Implementation:** in many cases, the IoT implementation process ends up being executed without a clear definition of the steps that must be followed and the necessary prerequisites for the CPLS to function properly. This implementation flow, non-existing or incompletely defined, ends up being accomplished in different ways and methods. For this digital transformation, some references are mentioned as models (frameworks), such as Bautu and Bautu (2016), Li et al. (2018) and Pomorstvo et al. (2015). These works highlight the recommendation that the transformation be well oriented, with rigor, method and speed, combining industrial logistic processes with manufacturing management processes and cyber-physical processes (Basco et al. 2018) to be successful.
c) **People training:** a large part of the good results that can be obtained with the implementation of IoT in industrial logistic processes and the creation of CPLS is directly related to the training of the people involved (Costa, 2017), since eventually these new processes will be implemented and managed by people.
d) **Standardization:** this is an important phase of the IoT implementation process in logistics and manufacturing processes, since non-standard processes tend to create shortcuts and sub-processes that, if not mapped, can generate many

complications and ultimately lead to the failure of digital transformation (CNI 2016; Comissió Indústria 4.0 2016; Ministero dello Sviluppo Economico 2017; Vaidya et al., 2018).

As suggestion for future works, this work recommends that the following be addressed: the definition of a CPLS design and implementation process that is flexible and takes into account the different factors that were mentioned in this work; the definition of a CPLS architecture to be used in this process to accelerate CPLS implementation, that highlights information exchange; the mapping of standardization needs within the different logistics perspectives, for a better communication among companies in a supply chain to occur.

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Concept of Design Activity Supporting Tool in the Design and Development Process of CPS

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Abstract. Cyber-Physical Systems (CPS) are systems that link cyberspace with the physical world by means of a network of interrelated elements (sensors and actuators) and computational engines. These different assets make it difficult to design properly and effectively with them all. Additionally, the designing of CPS requires multi-disciplinary project teams and the investigation of all activities which CPS should perform. The cooperation of specialists in only one area is often difficult. One can easily imagine what problems arise when designers from totally different fields have to cooperate. The designers have to share their knowledge and experiences, and to identify assets and activities which are necessary for the proper CPS functioning. Attention has to be paid not only to the process itself, product models, requirements and constraints, aspects of analysis and synthesis, automation tools, and the wider contexts of particular issues but also to the identification of design activities (performed by human designers) and requirements related to them. The proper identification process of the CPS activities allows to improve the design process through more precise and problem-activity-dedicated knowledge and activity-design models management.

Keywords. CPS, knowledge modeling, assisting systems in engineering

Introduction

Designing of CPS-class systems and designing of machines with CPS elements is a relatively new area of research. Although many works can be found in the literature related to this subject (e.g. [1-8]), majority of them concern the perspective narrowed down to a specific class of cases or solutions (e.g. [1, 5, 8]). Relatively few of them propose more general and universal approaches [2-4]. Also, some of them concentrate on the requirement that methodologies for CPS-design should be part of a multi-disciplinary development process within which designers would focus not only on the separate physical and computational components, but also on their integration and interaction [7]. Other authors, in the process of designing the CPS, focus on how to model and design the joint dynamics of software, networks, and physical processes [5], [8]. Inherited problem of safety connected with the use of the CPSs have also been in last few years subject to intensive research [9], [10] but still formal and recent regulations other than [11] are missing.

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The authors of this paper worked on developing a functional industrial project, the aim of which was to design a specific technical system with CPS elements – a tractor electronic transmission control unit (TCU). The project was started using classical design methods but in the course of the project the authors observed that this approach in multidiscipline environment was not sufficiently productive and thus a process-oriented approach was applied [12]. One of the final conclusions was also the suggestion that the whole process needs to be improved by creating a concept and then building a dedicated environment supporting this class of tasks in the following areas: informal and formal knowledge consolidation/storage/management [13], creation and simulation/analysis of CPS models [1, 2], supporting decision-making processes in design using the multidisciplinary design approach applied in selective way [14, 15].

The goal of the work carried out over a longer period was to create the concept of assisting software for designers. This software strives to support the design process of a product treated as a CPS [13, 16]. It was assumed that an assisting system allows design knowledge management at both the elementary level and at the level of entire classes of typical knowledge elements, or classes of elements requiring certain adaptive actions offering moving away from stereotype design solutions [17-22].

One of the basic elements of the assisting system is the concept of modelling project activity for projects with CPS components. This work is an attempt to create such a concept primarily based on information and knowledge from the real-life project.

1. Design activity modelling

1.1. Real-life project inspirations

The authors decided to consider, analyze and structure the design process by identifying and isolating individual design activities of the CPS system's real-life design task [13]: the design process of the electronic system (TCU) that controls the transmission and other selected tractor systems. The information, knowledge, that has arisen or has been accumulated as a result of the project implementation and the integrated documentation, was used as material for building the concept of individual components of the assistance software - including the conception of the project design activity which is the basic idea for the proposed approach [23-25].

The TCU project was developed by a team of designers - specialists from various disciplines, with a broad professional experience. Most of those designers had relatively rich professional biographies, and they had also a long-time experience in the team project work (9 - designers from 3 companies).

The main novelty in the project was the problem of specifying the scenarios for the functioning of a newly designed CPS device, both in an informal way - specifying the situations in which the structure should function, as well as formally modeling these situations to the extent that allows advanced analysis and design simulations.

In their analyses, the authors of the paper used project documentation and various additional information resources created during the TCU project implementation. One of the authors was also the member of the design team.

The designers, team members with large experience in specific design processes or some of their fragments referred most often to their projects using terms of design activities. Design activities can be associated with various groups of issues in the design processes which have usually arisen from issues encountered during designing or testing scenarios of CPS.

1.2. Details of initial design activity model

For modeling of the design activities, the authors of this paper use a classic approach from work [23]. The first stage of the analysis was to identify the design activities used by individual designers in their own original version. The original version was considered, i.e. the one with which the designers started to solve the problems. The result of this stage was the separation of three classes of activities:

1. such that did not require any modification in the case of the currently implemented project task,
2. those that required relatively simple modifications that could be made already at the stage of the first design iteration,
3. those that required far-reaching, unknown at the beginning, modification of all activity.

After analyzing the process of such selection, it was noticed that the activities belonging to class 3) generally resulted from the need to design CPS elements or to solve the encountered unforeseen issues. Their current form did not allow to solve the actual design problems. Usually, the goal of the activity was set and some new ideas (based on continuously improved input/output knowledge from previous version of activities) appeared to solve further newly identified problems.

The designers very often began to create one or several versions of the solution to the problem, experimented, drew conclusions and made improvements. They created new versions of those activities, tried to apply them to a given design problem. Sometimes an extensive research material was needed.

1.3. Results of initial design activity model application

Changes made to class 3) activities required repeated design analyses to be carried out as a whole process. This, in turn, could lead to the appearance of new modifications in the types of activities 2) and 3).

During the implementation of the design process, the gradual evolution of the form of considered scenarios for the functioning of CPSs, as well as adding new scenarios to the set originally assumed, was an additional element significantly broadening the scope of the entire design process. To a large extent, this was due to the new opportunities that arose as a result of project activities in subsequent iterations of the project (in the beginning, the semi-automatic gearbox TCU evolved into the concept of the semi-automatic/automatic gearbox TCU with on-line diagnosing and monitoring possibilities).

All activities were based on the knowledge of designers, which has significantly evolved in the design process. Their formal record was based on the concept of text and multimedia descriptions or on tools that automate these activities. The proposed approach assumed that the project activity may relate to a specific substantive issue. It can be modeled as a descriptive and multimedia resource [26, 27] functioning at three levels of accuracy (1-3, 3 most accurate) and can be modeled as an automation tool [28, 29] also at three levels of accuracy (1-3, 3 most accurate).

1.4. Concept of design activity template

Trying to build a more structured shape of the whole approach, the authors created the concept of a template related to activity (concept taken from [26, 23]), which may include both descriptive and multimedia components as well as automation components corresponding to the typology of [23].

Designing of CPS is usually multidisciplinary (in reality, in most cases these models are transdisciplinary) [14, 15], leading to the need to integrate many formal models with each other.

The following chapters present exemplary, detailed results obtained in individual groups of issues: analysis of implemented activities, modeling of activities evolution.

2. Analysis of performed activities

As part of the work, a number of activities was performed, which included familiarizing with the resources of knowledge used in the considered project task, classifying this knowledge, tracing both its sources and processes of its evolution in relation to the solved project tasks, mainly related to work scenarios of CPS. The listed knowledge resources, experiences and processes based on this knowledge and experience are schematically presented in figure 1. Both personal resources and team resources are visible. Knowledge evolution processes resulting from emerging tasks are presented. The entire resources of knowledge used are schematically marked at the top of the figure. The bottom part of the drawing presents scenarios for the functioning of the designed CPS in connection with the designers and their possessed and developing knowledge.

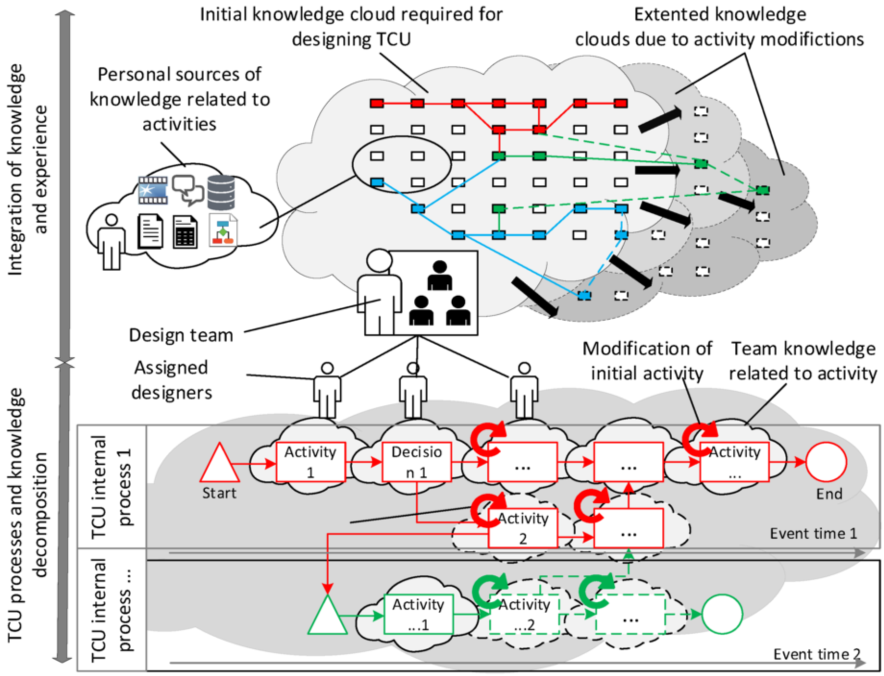

Figure 1. Schematic model of personal and team knowledge resources of designers in connection with implemented tasks - analysis of selected design scenarios.

2.1. Modeling, evolution of exemplary activity

The paper analyzes in detail the individual activities which were extracted from the project records and the reports. The following concept of their structuring and analyzing was used:

1. All members of the designing team were identified and their substantive profiles, professional experience, etc. were specified. This summary in a simplified form is presented in Table 1.

Table 1. List of chosen team members and their characteristics.

No	Team member	Area of specialty	Experience period (years)	Participation in activities (%)
1	Mechanical engineer No 2	Hydraulic systems, numerical simulations, tractor transmission and drivetrain, …	18	15
3	External mechanics and hydraulics expert	Tractor kinematics, optimization of gear change process, hydraulic systems, …	28	5
3	Electronics engineer and programmer	Electronics architecture, programmer, utility software development, …	15	10

2. Design activities used by individual team members were identified and listed for each team member. An example of a set of activities for one designer is shown in Table 2.

Table 2. List of chosen activities and their characteristics - performed by one of the design team members.

No	Design project activities of Mechanical engineer No 2	Characteristic of tasks in activity	(Group) Type of modifications
1	Analysis of hydraulic system supporting gear shifting	Analysis and modeling of gear shift process form hydraulic point of view	(3) complex modifications
2	Designing of gear shift process and characteristic	TCU software tests	(3) major modifications
3	Testing of gear shift process under the external load	Measurement setup and tests of implemented gear shift strategy (proportional valve characteristics of disengaged and engaged gear)	(3) major modifications
4	Model and data optimization	Analysis and adjustment of control parameters in TCU	(3) complex modifications

3. The activities and their elements were identified. For example, one of them is shown - with its structure - in Table 3.

Table 3. Analysis of hydraulic system supporting gear shifting activity and its structure.

No	Activity records	Form of representation	Format
1	Documentation of previous projects of a similar type	Descriptive documentation, numerical simulation model, measurement data, experimental and numercal results, …	Files (doc, xls, pdf, …), 2D and 3D models, experimental and simulation data,
2	Technical documentation of the hydraulic system	Descriptive documentation, specifications, data sheets, …	Files (doc, pdf), 2D and 3D models, graphics, pictures, …

No	Activity records	Form of representation	Format
3	Additional requirements from other activities, e.g. design of electronic unit	Descriptive documentations, required functionalities, planned TCU scenarios, risk report, …	Files (doc, pdf, xls, vsd, ..), paper reports, graphical files, pictures, video material , …
4	Experimental and numerical results and data	Experimental data, reports, video material and pictures from experimental investigation, …	Files (binary, mp4, doc, xls, raw, jpg…)

4. Identified version of specific components of the analyzed activities. An example illustration of the versatility of the activity component is shown in Table 4.

Table 4. Exemplary metamorphose of activity analysis of hydraulic system supporting gear shifting.

Activity	Version	Characteristics of additional problems solved or discovered
Analysis of hydraulic system supporting gear shifting	Initial	At the beginning only hydraulic system, which was directly supplying hydraulic pistons of clutch of proper gears, was analyzed. Experimental investigations shown improper fluctuations of pressure and the oil flow during shifting gears. This caused losing of clutches for a while after initial engagement and later second immediate engagement which caused overloading of transmission.
Analysis of whole hydraulic system of the tractor	After major modifications	To solve malfunctions of gear shifting process it was necessary to investigate whole hydraulic system of tractor including pumps, pressure relief valves, proportional valves. It was discovered poor manufacturing of hydraulic plate which caused leaks during gear shifting process. It was also necessary to introduce hydraulic accumulator to hydraulic system and adjust its volume and gas initial pressure. Although improvement in gear shift process was achieved still immediate engagement of clutch causing overloading was observed. It was discovered that, in spite of proper characteristic, control resolution of electronic components was to low causing too sharp increase in current supplying coil of proportional valves. It was necessary to include into analyzes measurements of electronic system and control signals.
Analysis of all systems and software controlling gear shifting process	After further complex modification	After including into optimization parameters related to hydraulic, electric, mechanical and software parameters it was possible to determine proper control characteristics assuring proper process of gear shifting under different loads of transmission. But this also shown that was necessary to rebuild software algorithms to include possible corrections due to temperature (to compensate changes in oil viscosity) at the end of the production line during cold pickup. It was also discovered that is possible to develop automatic valve characteristic adjustment software based on a few chosen measurements at the end of production line. Due to changes in this activity it was necessary to modify other activities related to designing of TCU. For. example it was necessary to adjust measuring system to measure signals from numerous different sensor (currents, torque, hydraulic pressure, oil flow, temperature, velocities of transmission shaft, engine velocity, engine torque, engine throttle, etc.) to enable analysis of measured values at the same time.

3. Design problem structure and evolving set of CPS functioning scenarios

The collected and analyzed documentation of the designed CPS also includes the perspective of so-called scenarios of CPS functioning. During the process of designing the TCU it is necessary to determine the set of tasks required to be performed to provide the required functionalities. For instance, the following scenarios were identified and considered: Power Shuttle (drive control providing the gear shifting under load conditions), Power Shift (semiautomatic control with the system adapted to the automatic control system), accelerating and stopping the vehicle, control of the differential lock of the rear axle, connecting/disconnecting of the front drive, connecting/disconnecting of the PTO shaft, blocking of selected gears with the Creeper gear option on, managing the Brake & Clutch function, etc. Based on identification of tasks, it is possible to develop scenarios to be performed by CPS. Proper identification of CPS scenarios allows for finding relation between the system components and transmitted information, such as electric signals. Each task in the scenario can be a source of multidisciplinary problems and risk which should be covered by the design process activities – cf. Table 4.

4. Functionalities of assisting software concerning activities

4.1. General model of activity

As a part of the project, a model of design activity was defined, its general structure, existing forms and individual components. A predefined typology of recognized types of activities was prepared as well as related keyword sets. The built representation of the activity allows to capture its development in the form of subsequent versions – cf. Figure 2. This formalism is presented in chapter 2 of this work in the form of tables filled with content from a real-life design task.

The part of the model described above focuses primarily on the aspects of storing information/knowledge, preserving information about the relationships between individual elements. It can be implemented in the form of an object-oriented model.

The model under consideration and its functioning in specific situations refers very strongly to the mechanisms observed by W. B Arthur in position [30]. The point here is how technology changes over time, how it evolves.

4.2. Modeling design activity development

Project implementers have also created concepts and prototype solutions in the field of model functionality, whose task is to offer the rapid and effective development of the object-oriented activity model.

During the analysis of the material documenting the sample task, attention was drawn to the large number of activities that already existed at the time of project implementation but required modification made by the designers. Such modifications can be performed in a basic way by editing the object model and attaching it to the rest of the model.

The authors drew attention to the fact that system users - CPS designers, in this type of circumstances, usually work in two areas: 1) conducting problem-oriented, filtered analysis of the content of previously created data structures and knowledge, 2) creating and analyzing hypothetical extensions of already created data structures and knowledge. Users are usually interested in more effective solutions than manual analysis or extension of the existing object-oriented model [19, 29].

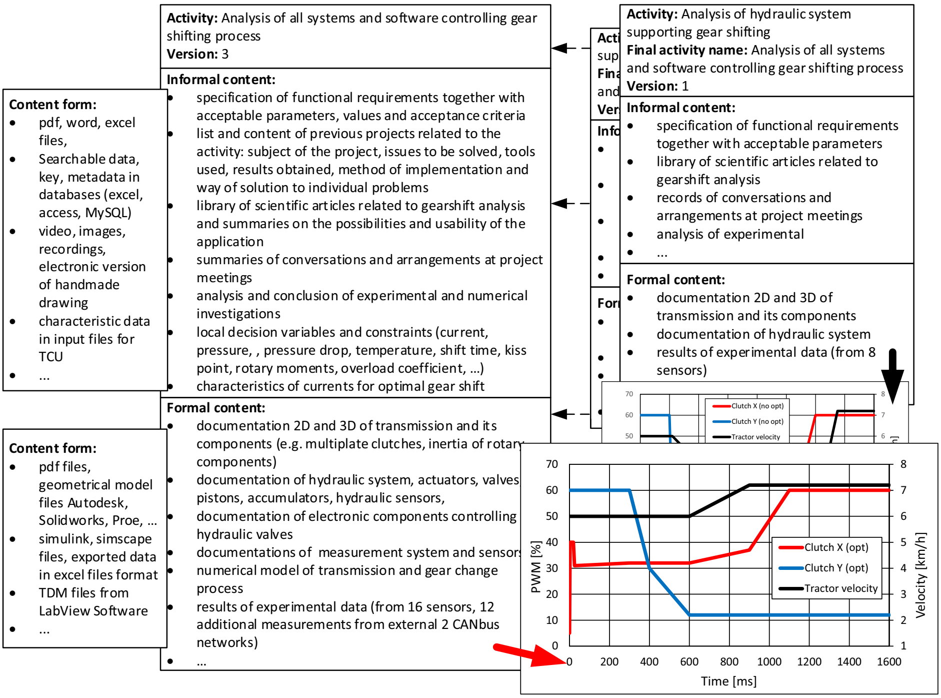

Figure 2. Schematic representation of the activity and description of its development.

4.3. Problem-oriented, filtered analysis

An important element of the newly modeled concept, of the assisting system, are mechanisms that allow for quick filtration of information and quick compilation of information depending on the contexts. It is equally important to search for the right form of a given activity, within a predefined set of forms.

4.3.1. Tools for fast visualization of activities and their contexts

The project assumes that work with the system should take place with a high level of search automation, appropriate for the problem being solved. In the absence of an existing, relevant instance of activity, helpful contextual information should be generated quickly, visualizing available, related instances of activity, their sources and examples of use in specific, previous projects.

4.3.2. Pre-configured activity templates

If a designer decides to create a new activity model, they are offered the option of using pre-configured activity templates – cf. Figure 3. For instance [30]: activity with substantial parallel extension, activity with hierarchical extension, etc.

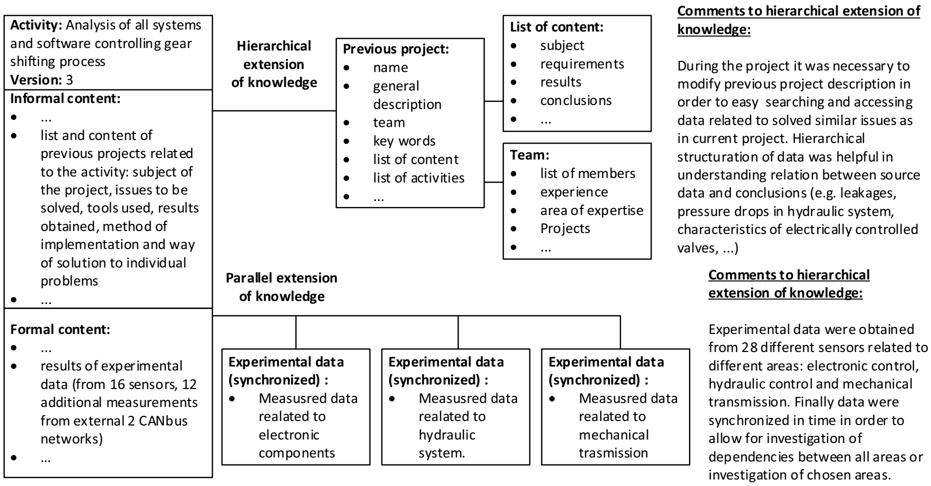

Figure 3. Example of activity template with parallel or hierarchical extension.

4.3.3. Final comments

All solutions developed to improve the process of creating advanced activity models depend very much on the data sets that are used at the time of testing.

The authors in their achievements relied on the documentation of an exemplary project task. The process of testing the concept consisted basically of analyzing different sets and subsets of information/knowledge elements and relationships between them. At that time this process was largely manual.

5. Conclusions

The authors, after completing the analyses presented in the work, attempted to create tools that allow to refer to specific functionalities, both their characteristics and resources, versions or applications.

The newly created functionalities will be tested on real-life examples of other CPS.

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Transdisciplinary Engineering for Complex Socio-technical Systems – Real-life Applications
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Reference Architectures for Industry 4.0: Literature Review

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Abstract. Currently, production systems are receiving the application of more advanced, integrated and connected technologies to optimize the performance of their manufacturing processes. The new technological solutions demand architectures that support intelligent solutions for a new digitalized industry. However, production systems already in operation have difficulty in implementing these technologies. The existing barriers limit the availability of the direct integration of different systems contemplated in an automation system architecture. This article systematically reviews the existing literature to portray the characteristics of each architecture and that can guide the adoption of new technologies. Through this review, emerging reference architectures were identified, such as RAMI4.0, IIRA, IBM Industry 4.0 and NIST Smart Manufacturing. In conclusion, the article presents a framework for considering which model best fits with the new technological solutions.

Keywords. Architecture model, Industry 4.0, reference model, smart manufacturing

Introduction

Currently, production systems are receiving the application of more advanced, integrated and connected technologies to optimize their manufacturing processes. The concept of Industry 4.0 encompasses these new technologies, such as IoT, Big Data, Analytics and others, which support new demands oriented to intelligent solutions [1].

However, production systems already in operation have difficulty implementing these technologies. Existing barriers limit the availability of directly integrating the different systems contemplated in an architecture of automation systems. Usually the communication between these existing automation systems is carried out in different layers and protocols, making the information have strong flow limitations within the working architecture. Establishing communication through all hierarchical levels of an automation platform to access process data freezes the system and makes it difficult to include intelligent systems. There are also other barriers that directly interfere with the application of new, more intelligent architectures, such as the incompatibility of communication between equipment from different manufacturers due to the existence of proprietary solutions and also the limitation of technological capacity to meet a more dynamic flow to enable a balance of performance during system operations. In many

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cases, the development of alternative solutions is necessary to enable communication between two equipment from different manufacturers.

In this sense, new technologies need to be integrated within an industrial equipment topology to directly carry out real time communication between all components of the system, enabling the adoption of intelligent solutions. The integration of a system will result a better physical configuration and functional performance and can be made possible through the application of automation architectures.

An automation architecture is a representation of the structure of a system in more detail, used for the system design, configuration of the physical assets, installation and their interfaces, specification of equipment and systems, selection of control technology, design of commands and realization of automation, communication and management functions [15]. The architecture definition process involves the search for alternative architectures or solutions within an automation platform through appropriate technological or technical elements that make up the system. This process is also used to define the requirements for each element of the system [14]. The notion of this process is abstract, but it is used to create, design or redesign products, services or companies. Designers and developers must be attentive in the choice and definition of an automation and control system, so that the project takes into account several criteria and that it can be in sync with technological advancements fulfilling the demands of new industrial solutions.

The new technological solutions demand the need for architectures that support intelligent solutions for a new digitalized industry. The present study aims to explore the architectural models already published through a systematic literature review.

1. Fundamental concepts

This chapter shows some fundamental concepts for the review, starting with the definitions of Industry 4.0 and architectural models.

1.1. Industry 4.0

The term Industry 4.0 appeared in mid-2011, during the Hannover technological fair (Hannover Messe). In 2012, a working group was created by the German Academy of Science and Engineering to carry out a report of recommendations for the implementation of Industry 4.0 with the German government. This group, chaired by Henning Kagermann and Siegfried Dais, presented in 2013 its final set of recommendations - the “Recommendations for implementing the strategic initiative INDUSTRIE 4.0”, which has been held until today as a great theoretical precursor to the fourth industrial revolution.

With the beginning of the use of the Internet of Things (in English Internet of Things - IoT) in the manufacturing environment, it is possible to predict a short and medium term future where, according to Kagermann [2], companies will establish global networks that will incorporate their machines, storage systems and facilities in the form of cyber-physical systems (CPS). In the manufacturing environment, these CPS comprise intelligent machines, capable of exchanging information autonomously, triggering actions and controlling each other independently. This facilitates fundamental improvements in the industrial processes involved in manufacturing, engineering, material use and supply chain and product lifecycle management. Smart factories employ a completely new approach to production.

1.2. Architecture

The terms corporate architecture or enterprise architecture define the set of methods and models used to represent an organizational structure, business processes and infrastructure. An architecture is the fundamental structure of a system, shaped in its components and mutual relations and with the environment, in addition to the guiding principles of its design and evolution. An architecture aims to have a broad view of the whole of a company [3]. The modeling of an architecture should allow to establish a relationship between the strategic layers of business, application and technologies [4]. The growing technological evolution coupled with the demand of the current market makes architectures increasingly complex and their modeling requires tools with the capacity to efficiently reproduce an organizational structural model.

A well-established architectural model also allows support in decision-making in line with the business strategy. The overall view of the plant makes it possible to more clearly predict the impacts of planned changes to be made to the system. Within this context, the biggest challenge of corporate architectures is to be able to align its business strategy to execution, making the planned strategy a reality within the company. A program for modeling and maintaining an architecture should understand the company as a whole, from the people, processes, information and available technologies. Even consider beyond the relations between them, also with the external environment. According to Zaidan [5], modeling allows a holistic view of the business environment, supporting governance and assisting decisions through the view of the current state of the business process.

Architectural modeling to address automation systems was implemented a long time ago using a hierarchical model with well-defined responsibilities, from sensors and actuators, to programmable-logic controllers (PLC), to Supervisory Control and Data Acquisition Systems (SCADA), to Manufacturing Execution Systems (MES), Enterprise Resource Planning Systems (ERP). This model is based on a commitment to cost, performance and integration between systems, respecting the hierarchy defined for the existing business processes.

Emerging technologies are changing the way production systems are structured and operated, new concepts are inserted in solutions such as IoT, cloud computing, Big Data, analysis, additive manufacturing, collaborative robotics, mobile technologies, among others. System integrators are struggling to incorporate these technologies into existing systems, which sometimes have an impact on business models. This poses new challenges for automation systems

2. Method

This paper uses the ProKnow-C method for conducting the systematic literature review [16]. This method (Figure 1) starts with the definition of the search axes (themes that determines the search), followed by the stipulation of the search expression. Subsequently, reference databases on which to search are selected.

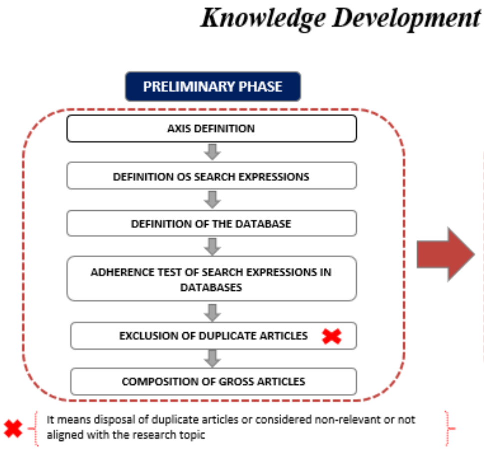

Figure 1. Knowledge Development Process-Constructivist.

To check if the selected search expression is adequate or if there are other terms that better represent the research theme, it is suggested to read three articles obtained in this preliminary search. If these five articles are considered inappropriate, it will be necessary to change the search term and reinsert it in the databases.

After the search expression adherence test, it is necessary to exclude duplicate articles (usually found in different search databases). Then, the titles of the articles should be read with the ones considered not aligned with the theme discarded (do not specifically address the research theme).

The next step is to verify the scientific relevance of the selected articles, examining the number of citations of the articles and the year of the article (written in the last 5 years).

Then, the abstracts of the articles should be read with the ones considered not aligned with the theme discarded (articles not specifically addressing the research topic), followed by the evaluation of the availability of the articles.

Next, the full articles must be read with the exclusion of those considered not aligned with the theme (considered to not specifically address the research theme), hence, builgind the final bibliographic portfolio of the research theme.

Based on the composition of the bibliographic portfolio, the analysis must be performed by verifying the evolution of the number of articles over the years, the main vehicles of publication, authors and references in addition to the network of keywords and the author's citation matrix.

3. Results

This section shows the positioning of the bibliographic portfolio followed by its analysis and, finally, the proposal of the research agenda.

3.1. Composition of Bibliographic Portfolio

Axes A and B (research themes) used consisted of "Industry 4.0" and "architecture model", respectively. Inserted in each axis, the following search expression was chosen, as shown in Figure 2.

Axis A: Architecture	Boolean operator	Axis B: Industry 4.0
("model architecture" OR "reference architecture" OR "reference architecture i4.0")	AND	("industry 4.0" OR 4th industrial revolution" OR "smart manufacturing"OR "internet of thing" OR "ïndustrial of things")

Figure 2. Axis A and B with their respective keywords.

In addition, it was decided to restrict the search for articles published in journals and conferences, written in English and published online until the end of July 2019, considering only Scopus as the database for the composition of the bibliographic portfolio. With the insertion of the search expression in their respective databases, the preliminary results showed 81 articles.

In the next step, to check if the selected research terms are appropriate or if there are other terms that better represent the research topic, the recommendation of reading three articles was followed, as shown in Table 1.

Table 1. Adherence search expression test.

	Articles description
1	Gabriel, M., & Pessl, E. (2016). Industry 4.0 and sustainability impacts: critical discussion of sustainability aspects with a special focus on future of work and ecological consequences. Annals of the Faculty of Engineering Hunedoara, 14(2), 131. Keywords: Industry 4.0, small and medium-sized enterprises, sustainability impacts
2	Stock, T., & Seliger, G. (2016). Opportunities of sustainable manufacturing in industry 4.0. *Procedia Cirp*, *40*, 536-541. Keywords: Sustainable development, Factory, Industry 4.0.
3	Kiel, D., Müller, J. M., Arnold, C., & Voigt, K. I. (2017). Sustainable Industrial Value Creation: Benefits and Challenges of Industry 4.0. International Journal of Innovation Management, 21(08), 1740015. Keywords: Industrial Internet of Things; Industry 4.0; Triple Bottom Line; sustainability; expert interviews; multiple case study; qualitative study; manufacturing companies; German industry sectors.

Positive adherence by research themes can be observed, resulting in articles dealing with two research themes (industry 4.0 and architecture model) simultaneously, in addition to keywords similar to the search expressions.

Then, the refinement phase began, reading the titles of the 81 articles and discarding those considered not aligned with the theme (they do not specifically address the two themes), resulting in 75 articles.

Of these 75 articles, their scientific relevance was inspected, examining the year of publication and the number of citations. It can be noted that the articles were written recently, in the last 5 years, with great growth in the year 2017.

However, a small number of citations (SCOPUS was used) can be perceived when verifying scientific relevance, only two articles exceeding 100 citations. This can be explained by the agglomeration of publications in the these two years (2017-2018), which causes a low level of exposure for the scientific community. In view of this particular fact, no article was rejected and all 100 were considered scientifically relevant.

3.2. Architecture References

Considering that an rchitecture is a model of representation of a structure capable of representing the correlation of several systems [6], after reading the 75 selected articles by applying the ProKnow-C method, six architectures were identified. These architectures are the ones that could be used to develop an intelligent manufacturing solution and promote systematic standardization within Industry 4.0/smart manufacturing:

- Reference Architecture Model Industrie 4.0 (RAMI 4.0) [7]
- The Industrial Internet Reference Architecture (IIRA) [8]
- IBM Industry 4.0 Architecture (IBM)[9]
- Smart Manufacturing Ecosystem (SME)[10]
- Intelligent Manufacturing System Architecture (IMSA)[11]
- Industrial Value Chain Reference Architecture (IVRA) [12]

A summary of these architectures is presented next.

3.2.1. Reference Architecture Model Industrie 4.0 (RAMI 4.0)

The three-dimensional relationship guided by the RAMI 4.0 model makes a relationship between hierarchies, functions, and product lifecycle (Figure 3). There are 6 layers of integration responsible for making this relationship between all components of the architecture:

- **Business layer:** describes the company's organizational culture with business models, financial control and the legal sector.
- **Functional layer:** describes the technical and logical functions for the functions to be followed.
- **Information layer:** describes all information contained, whether it is real-time information, such as production data, or as information about rules or internal rules of the line.
- **Communications layer:** describes the data standards to be followed for industry 4.0 standardization.
- **Integration layer:** describes the acquisition and digitization of information, that is, the transformation of data from nature to measurable physical quantities through the digitization of information.
- **Asset layer:** represents the existing physical elements, such as equipment or product of the line, something that serves as an information base for other elements or functions.

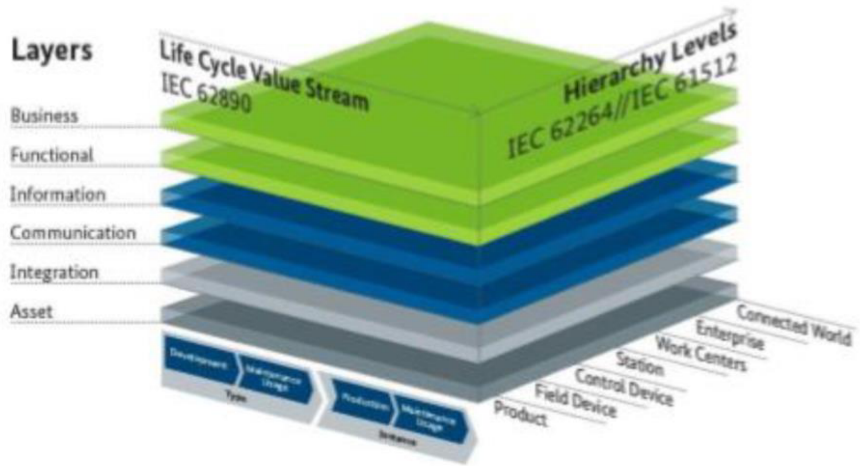

Figure 3. Idea of RAMI 4.0 [7].

3.2.2. The Industrial Internet Reference Architecture (IIRA)

The Industrial Internet Reference Architecture (IIRA) provides a five-layer description of the functions in an industrial system, their interrelation, structure, and interactions:

- **Business layer:** functions that allow operation in any industrial system.
- **Application layer:** functions that allow the management, monitoring and optimization of control systems through application logic.
- **Information layer:** functions that support the provision, transformation, modeling and implementation of data.
- **Operations layer:** functions that are responsible for provisioning, managing, monitoring components throughout their life cycle.
- **Control layer:** functions that enable the control of an industrial system.

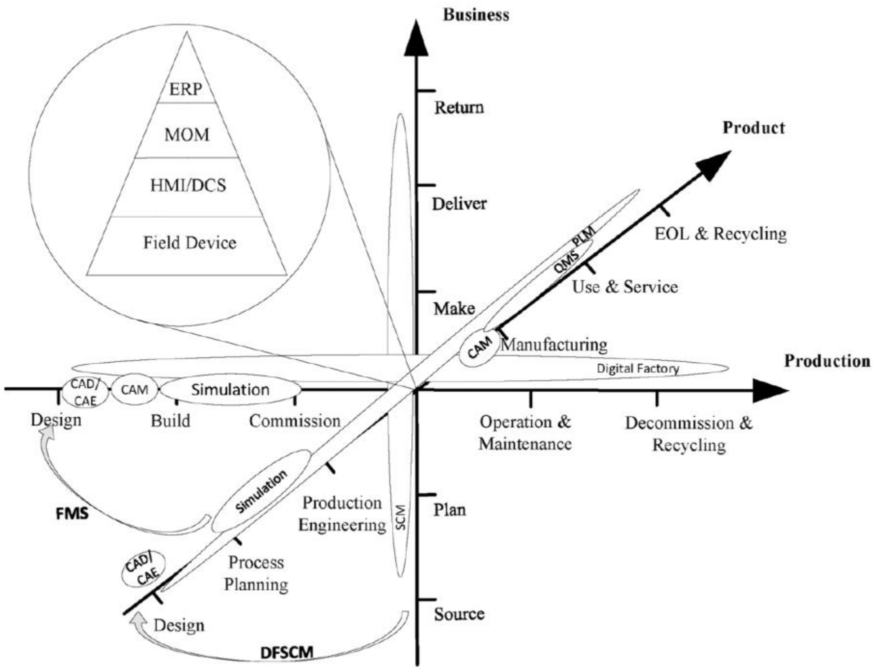

Figure 4. Idea of IIRA 4.0 [14].

3.2.3. IBM industry 4.0 architecture

The IBM industry 4.0 architecture proposes a solution based on three levels:

- **Edge level:** is widely considered a trade-off and balance between enterprise constraints, management and operations considerations, latency and performance requirements, and data privacy constraints.
- **Plant, factory or shop floor level:** the practice is to implement in each plant a service bus, often called a plant service bus (PSB), to manage local activities and connectivity with the physical environment: PLC, SCADA, OPC.
- **Enterprise or back-end level:** at the enterprise level, enterprise- or industry-specific applications are deployed for various needs: asset management,

mainterance management, consolidated data historian, ERP, optimization production scheduling, PLM, and supply chain management.

3.2.4. Smart Manufacturing Ecosystem (SME)

The Smart Manufacturing Ecosystem (SME), related to smart manufacturing, is organized along four dimensions.

- **Product lifecycle: t**he Lifeclye is from design, process planning, production engineering, manufacturing, use & service, to EOL & recycling.
- **Production lifecycle:** the lifecycle is from design, build, commission, operation & maintenance, to decommission & recycling.
- **Business**: The supply chain cycle is from source, plan , make, deliver and return.
- **Manufacturing pyramid**: this dimension is based on the IEC/ISO 62264 model.

3.2.5. Intelligent Manufacturing System Architecture (IMSA)

Intelligent manufacturing is considered to be the expression for the Chinese Industry 4.0 [13]. Intelligent Manufacturing Systems Architecture (IMSA) observes Smart Manufacturing units from three-dimension:

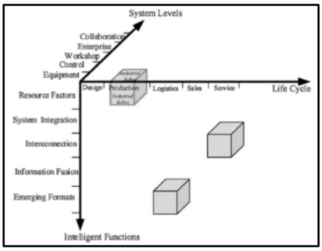

Figure 5. Idea of IMSA[14].

Intelligent functions: Collaboration, Enterprise, Workshop, Control and Equipament.
Lifecycle: Design, Production, Logistics and Service;
System levels: Resource Factors, System Integration, Interconnection, Information Fusion and Emerging Formats.

3.2.6. Industrial Value Chain Reference Architecture

Industrial Value Chain Reference Architecture (IVRA) observes Smart Manufacturing units from 3 views:

Asset view: The view shows assets valuable to manufacturing enterprises. Four classes of assets (personnel, process, product and plant) are distinguished.
Activity view: The activity view is composed of the cycle of Plan, Do, Check and Action, which is the core methodology of total quality management and business process continuous improvement.
Management view: The management view shows targets of management. Quality, cost, delivery accuracy, and environment are included.

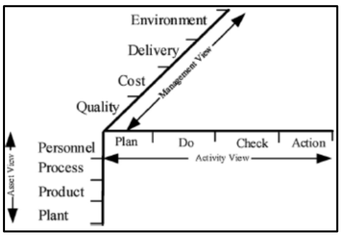

Figure 6. Idea of IVRA[14].

3.2.7. Summaries on Architectural models

Summarizing the works found above on various architectural models, we can obtain the result as shown in Table 2. This table is divided into three dimensions with its subdivisions. Each dimension of the table represents a perspective that needs to be considered when analyzing an architecture (domain, technology and information).

The information perspective is related to development in different layers and directions. Information systems are strongly linked to the design process, cloud databases and networked technologies. The technology perspective supports intelligent manufacturing, such as: new equipment, factory techniques, energies and materials. The domain perspective is related to management processes, product lifecycle, production lifecycle and supply chain.

Table 2. Summaries on architectural models.

DIMENSION	**SUB-DIMENSIONS**	**RAMI 4.0**	**IIRA**	**IBM**	**SME**	**IMSA**	**IVRA**
DOMAIN	HIERARCHY LEVELS	X	X	X	X	X	X
	PRODUCT LIFECYCLE	X	X	X	X	X	X
	BUSINESS LIFECYCLE	X	X	X	X	X	X
	PRODUCTION LIFECYCLE	X	X	X	X	X	X
	MANUFACTURING MODE DEVELOPMENT	X	-		-	-	-
TECHNOLOGY	NEW EQUIPMENT	-	-	X	-	X	X
	NEW MANUFACTURING PROCESS TECHNIQUES	X	-	-	-	X	X
	NEW ENERGY	X	-	-	-	-	X
	NEW MATERIALS	-	-	-	-	-	X
INFORMATION	FUNCTION LAYERS	X	-	X	X	X	-
	COMMUNICATION TECHNOLOGY DEVELOPMENT	X	X	X	-	X	X
	NETWORK TECHNIQUE DEVELOPMENT	X	X	X	-	X	X
	DATA STORAGE TECHNOLOGY DEVELOPMENT	-	X	-	-	-	-
	DATABASE TECHNOLOGY DEVELOPMENT	X	-	-	-	X	-
	IT INFRASTRUCTURE DEVELOPMENT	X	X	-	-	X	X
	SIMULATION TECHNOLOGY DEVELOPMENT	X	-	-	X	-	-

4. Conclusion

This work presents a systematic review of the literature, with an overview of captured architectural models for Industry 4.0 and a brief comparison of them.

When considering the results of the present study, several limitations should be noted. First, the articles were collected in only one database (Scopus). Second, because the search criteria restricted the language of the article collected to English, existing searches that have been published in other languages have been excluded. Third, only articles from magazines and conferences were considered. Therefore, this review could be more comprehensive if more databases, languages and types of vehicles were also taken into account. However, as a systematic review of the literature, appropriate restrictions must be specified for the review to be viable.

Intelligent manufacturing is related to information and communication technology, industrial technology and management technology. The intelligent manufacturing system is a complex, large-scale system that must encompass these technologies. In this sense, standardization is a powerful tool to drive the development and implementation of smart manufacturing technologies. Currently, existing standards are organized into related architectures. The article presents the main existing architectural models. Among the models, the RAMI model stands out, which is presented as a relevant reference, with a focus on guiding the development of a reference models, from a more technical point of view, through different performance layers of the aspects facing the shop floor to strategic decisions by business areas. Future research can be conducted to identify which existing architecture models address the views of Industry 4.0 using multicriteria methods.

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Human-Centred Design

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Transdisciplinary Assessment Matrix to Design Human-Machine Interaction

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Abstract. Successful interaction with complex systems is based on the system ability to satisfy the user needs during interaction tasks, mainly related to performances, physical comfort, usability, accessibility, visibility, and mental workload. However, the "real" user experience (UX) is hidden and usually difficult to detect. The paper proposes a Transdisciplinary Assessment Matrix (TAS) based on collection of physiological, postural and visibility data during interaction analysis, and calculation of a consolidated User eXperience Index (UXI). Physiological data are based on heart rate parameters and eye pupil dilation parameters; postural data consists of analysis of main anthropometrical parameters; and interaction data from the system CAN-bus. Such a method can be adopted to assess interaction on field, during real task execution, or within simulated environments. It has been applied to a simulated case study focusing on agricultural machinery control systems, involving users with a different level of expertise. Results showed that TAS is able to validly objectify UX and can be used for industrial cases.

Keywords. Human-centered design, User eXperience (UX), Ergonomics, Human Factors, Workload

Introduction

Design of complex systems has to take into account numerous requirements, merging both technical and social aspects, according to a typically transdisciplinary approach [1]: from engineering issue like functionality and performance, to user requirements, business aspects, until government regulations. Indeed, systems has to work properly, but also satisfy the users' needs during their use. The introduction of ergonomics or human factors (HF) in engineering purposely aims at considering both technical and social issues in the development of complex systems, including the human perspective into engineering design [2]. Indeed, HF is a multidisciplinary science that involves different disciplines (e.g., psychology, anthropometry, biomechanics, anatomy, physiology, psychophysics) all related to the study of the interaction between humans and the surrounding environment. HF suggests to start from the study of the characteristics, capabilities and limits of the user, and applies it to the design of a system

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as well as to the evaluation of the human-machine interaction. This approach is fundamental to guarantee the best possible interaction with the user.

This research focuses on the design of tractor cabins. The cabin, indeed, represents the main workspace but also the central interface between the user and the machine, where the interaction happens. In particular, modern machines have rapidly evolved in the last ten years, in terms of technologies on board, and nowadays traditional means (e.g., leverages, buttons) coexist with novel technologies (e.g., touch screens, multi-functional armrests) [3]. New technologies have been frequently added to traditional tools with the aim to improve user comfort and task efficiency, and reducing the physical workload. However, only in few cases there was a clear planning about how the new interaction is taking place, and how is the generated user experience (UX). In fact, working with these new types of machinery involves a bigger mental workload, requiring an extensive expertise and greatly modifying the final UX with respect to older systems. As a result, in some cases new devices included on-board are not used properly in practice by users, or even risk to complicate the human-machine interaction.

The paper presents a transdisciplinary method based on collection of physiological, postural and interaction data for the analysis of the human-machine interaction. Such a method has been defined transdisciplinary as it includes both technical and social aspects and certainly involves people from practice. Technical science concerns with the design of machines, interfaces and information system. Social science assists in identifying the needs of users in order design usable and useful interfaces and interaction systems [4]. About the societal impact, the presented methodology could enhance the quality of products, helping engineers and designers in detecting possible issues in advance and including human factors along the design process.

1. Research Background

Ergonomics and HF aim at assuring the human comfort and safety, and consequently improving the work performance. Indeed, there are many factors both physical and cognitive, that affect the users' performance and the quality of human-machine interaction: from physical workload, due to uncomfortable postures, to task complexity, overload of information, or time pressure [5]. Moreover, the response to same stimuli is not equal among different users, since every user will reply according to his/her own capabilities. UX is based on the personal perceptions and responses that result from the use or anticipated use of a product, system or service", including users' emotions, beliefs, preferences, perceptions, physical and psychological responses, behaviours and accomplishments that occur before, during and after use [6]. It can be stated that UX during human-machine interaction can be analysed by a set of objective parameters, referring to the three above-mentioned aspects. For instance, measuring the user's physiological response allows creating knowledge about how he/she is interacting with an industrial machine / system thanks to objective data. Such knowledge can be used to design human-centred, ergonomic, and more usable systems. Moreover, the analysis of the postures assumed during the interaction can express the level of physical comfort. Finally, interaction data are crucial for the UX analysis during interaction with control and management systems, like dashboards, cockpits or joysticks.

According to the scientific literature review, the most reliable set of physiological parameters to be used to measure the UX are: heart rate (HR) defined as the number of heart beats per minute, heart rate variability (HRV) defined as the temporal variation between sequences of consecutive heart beats), pupil dilatation (PD) and eye blinks. Heart monitoring is one of the most common methods used especially in medical and fitness contexts. Nowadays, HR and HRV measuring is quite simple and cheap thanks to low cost wearable sensors. Previous researches showed the correlation between HR and HRV with the physical and mental workload [8]. In addition, pupillometry and electrooculography are nowadays widely diffused, due to the increased performance of eye-trackers, the improved ergonomics of devices (e.g., glasses) and the gradual cost reduction. The most frequently parameter used is the PD, which provide information on the individual's attention source and stress [9] [10]. It has been found that PD changes under stress situations and can be measured by the dilation mean value. Also, the increase of the eye blink frequency and latency, that can be deduced together with PD analysis using an eye-tracker, can highlight an increase in the human workload [11]. Eye-tracker analysis allows also to investigate visibility: eye movements data can be also used to map the visual interaction into two main modalities: gaze fixation data are then analysed to visualize the so-called gaze plot, and a heat maps to show the most visualized areas. Gaze plot indicates the attention span of each visualization and a corresponding time series, whereas heat map shows the frequency of each gaze.

As far as the postural comfort is concerned, there are several well-known methods. They are mainly based on user observation and analysis of anthropometrical data and joint angles. For instance, the National Institute of Occupational Safety and Health (NIOSH) allows measuring the user parameters relating to the level of musculoskeletal comfort considering also the intensity, frequency, and duration of the particular task [12]. There are also specific methods, to be used according to the specific context of use and type of tasks: Ovako Working posture Analysis System (OWAS) [13], Rapid Upper Limb Assessment (RULA) [14], Rapid Entire Body Assessment (REBA) [15], or the most recent Workplace Ergonomic Risk Assessment (WERA) [16]. More generally, single joint angles of the diverse body parts can be analysed and compared with a set of pre-defined comfort angles, according to the Dreyfuss 3D study [17]. Such comfort values have been defined from a variety of sources, from academic and NASA studies, to evaluate the range of comfortable bending of every joint for a user driving a machine in a determined position.

Finally, interaction with controls is objectify by the system Controller Area Network (CAN-bus). This is the vehicle bus standard designed to allow microcontrollers and devices to communicate with each other's' applications without a host computer. For each device, the data in a frame is transmitted sequentially but in such a way that if more than one device transmits at the same time the highest priority device is able to continue while the others back off. Frames are received by all devices, including by the transmitting device. CAN data has been recently used for UX testing [18].

In addition, the user comfort can also be assessed considering the subjective impression. Subjected judgement is an important aspect in UX, due to the individual nature of the outcome to be analysed. For these purposes, self-reported questionnaires are frequently used before and after task execution with two different purposes. Pre-questionnaires aim at providing an ex-ante evaluation of the users' habits and interaction style, in order to create a baseline to properly interpret the analysis of data collected during task execution. Post-questionnaires aim at self-reporting the level of comfort and stress in order to rate the perceived workload in order to properly assess the given performance.

For this study, focusing on tractor cabin design where one of the main activities is driving, two types of pre-assessment questionnaires have been selected from literature:

DSQ (Driving Style Questionnaire) and LCB (Locus of Control of Behavior scale). DSQ is a psychological questionnaire for the evaluation of the users' driving style [19]. It deals with a self-assessment 15-item questionnaire that uses a six-value scale for the identification of the user's driving profile. LCB has been defined as the degree to which an individual can perceive a causal relationship between his own behaviour or actions and ultimate consequences or reward [20]. LCB questionnaire is a 17-item Likert-type scale to measure the extent to which a person perceives events as a consequence of his own behavior and believes that they are potentially under personal control (internal locus of control), or instead that events are determined by fate or outside forces that are beyond his own personal (external locus of control). In this study, LCB allows having information on the degree of participation of the user in his vehicle and task execution, in order to better interpret their feedback, actions and reactions. About post-questionnaire, NASA-TLX (Task Load Index) is widely used to provide a subjective, multidimensional assessment of the perceived workload [21]. NASA-TXL is applied to a variety of domains, including aviation, healthcare and other complex socio-technical domains.
Nowadays human monitoring is a relevant topic, due to the increasing attention to new technologies for preventing accidents and providing assistance during the driving task (e.g. Advanced Driver Assistance Systems, ADAS). Vehicles are getting ready with biometric low-cost tools, today commonly used in fitness, in order to carry out real check-ups of the driver then the passengers, reporting in real time health problems or inhibiting driving hazards. These systems focused on responding effectively to actions taken by the driver to control the vehicle optimally and safely, but don't concern with the psychological state of the driver [22]. Despite this, many studies demonstrated the correlation between psychological features and physiological characteristics of the driver, so the same tools used in driver health monitoring (e.g., EEG, ECG, GSR, facial recognition) can be used to recognize emotions as demonstrated in several studies [23, 24, 25] and, more broadly, UX. Different protocols for driver emotions assessment have been recently developed to comprehend how they can affect drivers performance [26] but they aren't able to give a feedback for the enhancement of the vehicle. On this topic, a technological set-up has been studied and tested in order to monitor driver's workload in real time, with the final aim to configure and adapt the car interfaces and according to the specific driver's needs [27]. The research novelty is the application of human monitoring tools for human-centered design, testing in an early phase the system ability to quench the user needs. Moreover, this approach could be applied not only for commercial vehicle but for a wide range of vehicles (e.g. buses, tractors).

2. Research Approach

The research approach integrates the analysis of both physical, physiological and interaction parameters in order to objectify the users' experience and the perceived workload. In particular, a general framework for the analysis of the human-machine interaction has been defined, as presented in Fig. 1. The research approach is based on the combination of:

- Physiological data (HR/HVR analysis and PD analysis);
- Postural data (postural analysis by Dreyfuss 3D);
- Interaction data (CAN-bus data analysis about command activation on the machine interface);

- Subjective data about:
  - users' personal data (anamnestic data questionnaire)
  - users' driving style and locus of control (DSQ and LCB pre-questionnaires),
  - perceived workload (NASA-TXL post- questionnaire).

For each task, data are collected before, during and after task execution with the involvement of users, and properly synchronised and correlated in order to have valuable results. Synchronisation of data collected during task execution is basically a time synchronization. Data correlation is firstly based on the Pearson's correlation *r* to quantify the reliability of the data collected, expressing the relationship between two variables. Indeed, the Pearson's correlation does not include cause-effect relations, but only mere relationship between variables, thus allowing to affirm the systematic relationships between two variables, but not to determine reciprocal cause and effect. Such correlation also considers the subjective post-assessments results, on the basis of the baseline created for each user thanks to the pre-questionnaires data.

Finally, the collected data are properly "summed up" considering a weighted factor (0, 3, 9) according to the satisfaction of the pre-defined UX target values, to fill the so-called TAS (Transdisciplinary Assessment Matrix). UX target values are reference targets to judge if the measured parameters can guarantee a positive UX, according to the following scale:

- Green mark = the UX target is guaranteed, good design!
- Yellow mark = the UX target is close; design could be improved to achieve the comfort level until the green mark;
- Red mark = the comfort is compromised, with risk of excessive physical and cognitive workload. Design could be urgently improved.

At the end, the UXI (UX Index) is calculated as the sum of all weighted values collected, in a discrete way, for all the time step. In order to have a continuous time trend of the UXI function, a linear interpolation between the detected points is expected. The result is then compared with the perceived comfort from NASA-TXL.

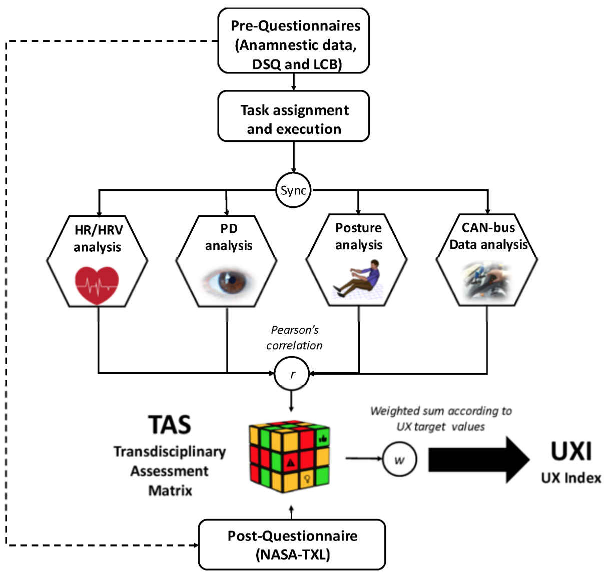

Figure 1. TAS (Transdisciplinary Assessment Matrix) framework for Human-Machine Interaction analysis.

The research approach can be practically adopted by a set of metrics, able to measure the users' conditions and interaction, and tools able to collect the necessary metrics. Table 1 shows the selected metrics and tools used to collect the different type of data, as described in the research framework. In particular, the tools adapted are as follows:

- Physiological data (i.e., HR/HVR analysis and PD analysis) are monitored during tests with users by wearable technologies, respectively Zephyr BioSensor BH3 and Tobii eye-tracking Glass 2;
- Postural data are retrieved by the user's motion capture by a GoPro Hero+ camera, which data are integrated with a human simulation system (Siemens Jack, OPT package) to carry out Dreyfuss 3D postural analysis. A professional motion capture system cannot be used due to difficulties to collect on-field data;
- Interaction data are collected by the machine CAN-bus, which records the specific command activation on the machine interface, and post-processed by CANAnalyzer software toolkit);
- Subjective data about pre-assessment (i.e., users' personal data, driving style and locus of control) and post-assessment (i.e., perceived workload) are carried out by fill in paper-based questionnaires.

Table 1. Metrics and tools for data collection according to the TAS framework

Data	Metrics	Tools
Subjective data	Pre-Questionnaires: - **DSQ** (Driving Style Questionnaire) - **LCB** (Locus of Control of Behavior scale) Post-Questionnaire: - **NASA-TLX**	Paper-based
Physiological data	**HR** (Heart Rate) and **HRV** (Heart Rate Variability): - RR deviation in frequency domain - RR mean value in frequency domain **PD** (Pupil Diameter): - PD mean value in time domain	Biosensor: Zephyr BH3 + OmniSense Eye Tracker: Tobii Glasses 2 + Tobii Pro
Postural data	Angles of comfort: - **Dreyfuss 3D** angles analysis in time domain	Motion capture: GoPro camera + Siemens Jack
Interaction data	**CAN-bus** user input: - no. of clicks / actions - time to find a command	CAN-bus data: Telemaco + CANalyzer

3. Experimental study

The experimental study was developed in the University Lab with the scope to validate the proposed TAS framework for the design of human-machine interaction, to be subsequently applied on tractor's cabins in collaboration with CNH Industrial. The final aim is to define a set of design guidelines to improve the UX of the operators, using their products (tractors). As the study was developed in Lab, a simulated driving activity was asked to users using a mock-up replicating the tractor seats and the main control board. Fig.2 shows the simulation environment in Lab. Fig. 3 shows the experimental set-up adopted for tests with users. Each testing session was structured as follows:

- Pre-questionnaires (5 mins);
- Monitoring tools wearing and tools set-up (3 mins);
- Tools calibration (1 mins);

- Baseline on the mock-up: seating relaxed (2 mins);
- Task execution (5-10 mins);
- Relaxing (1 mins);
- Post-questionnaires (3 mins).

20 users with different level of expertise were involved in the experimental tests. For each user, UX target values were defined during the baseline analysis and checked during the final relating phase. Data collected from all users were analysed and synchronized. Matlab was used for data post-processing and correlation. In particular, the beat-to-beat interval sequence (RRcurve), pupil diameter measures (PD) and Dreyfuss 3D angles data are post-processed. All these parameters have therefore been considered as input of the TAS, that filtered the input signals, associates with each signal certain values based on pre-set thresholds, and produced a continuous comfort function. In order to support TAS, classic assessment tools such as Heat Maps and Gaze Plots of fixations and assessment questionnaires have been added. Moreover, the use of pre- and post-questionnaires were found remarkably useful, as they provide support to correct data interpretation. Indeed, the subjective impressions represented the main criterion to judge the UX target value taken during the baseline.

Figure 2. Simulation environment in Lab: mock-up used during user testing (left) and virtualization (right).

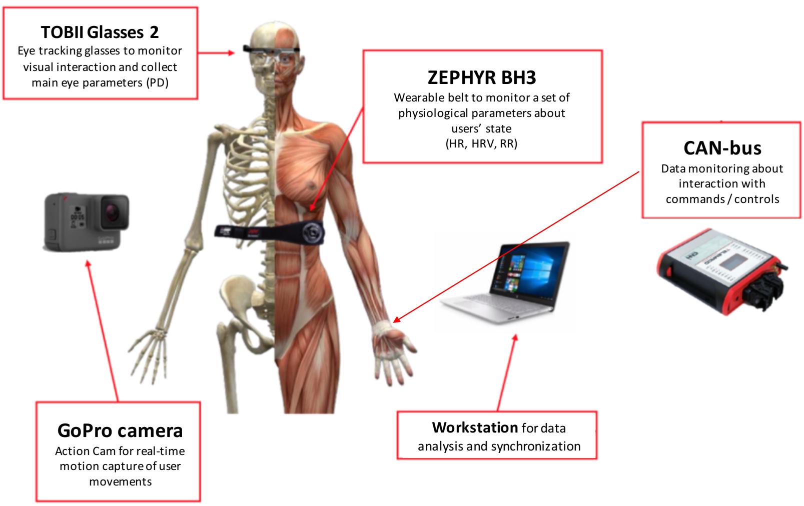

Figure 3. Experimental set-up.

4. Results

Experimental results showed a good correlation between the comfort index obtained by the new approach and the subjective questionnaires. In particular, UXI values on 17 out of 20 users are in line with the evaluation of the perceived comfort in NASA-TLX. The mental workload seems to be higher during specific phases (e.g., during manoeuvres like direction reversal), when users had to interact with various commands. It emerges from the analysis of the beat-to-beat interval sequence (RR curve), turned out to be a fairly reliable metric to assess the mental load (i.e., low values correspond to poor ability to cope with situations stressful). Similarly, pupil diameter (PD) data are used to confirm this state. This feature make understand how commands are used in different situations, from higher psychophysical commitment phases from less critical ones. Contrarily, during the driving phase, the mental effort is lower but users are more stressed from the physical point of view. Indeed, the use of some commands, especially the gear lever forces the drivers in a stressful position, highlighted by the UXI and confirmed by Dreyfuss 3D data (compared to the condition of optimal comfort). Moreover, the use of the CAN-bus helps to recognize commands, levers and buttons that are poorly positioned and that are advisable to move in another location. A further assessment with Heat Maps and Gaze Plot, could aid in detecting commands that are not sufficiently visible. As expected, people with a poor experience in tractor driving showed up a lower mean value of UXI than the more experienced ones, demonstrating a different level of effort in accomplishing the tasks.

5. Conclusions

This paper presented a transdisciplinary methodology to support the design of systems based on a multi-dimensional analysis of different parameters. It allows to have a holistic assessment of the interaction quality and to find out specific correlations between the assessment metrics, such as Heart Rate (HR), Heart Rate Variability (HRV) and pupil diameter (PD), with the use of commands as registered by the system CAN-bus. This approach fuses different branch of knowledge in order to assess the UX, according to a transdisciplinary approach. The combination of human monitoring and ergonomics methods allowed the evaluation of the users' physical comfort and mental effort. Results showed that TAS is able to validly objectify UX and quickly identify system design optimization in terms of interface layout and workstation features. The combined evaluation of mental and physical workload could enhance the quality of product, revealing possible issues. Therefore, TAS could be an interesting tool that provides feedback during the design stage. TAS is ready to be applied to industrial cases.

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Application of Innovative Tools to Design Ergonomic Control Dashboards

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Abstract. Designing highly usable and ergonomic control dashboards is fundamental to support the user in managing and properly setting complex machines, like trains, airplanes, trucks and tractors. Contrarily, control dashboards are usually big, intrusive, full of controls and not really usable for different users. This paper focuses on the re-design of an ergonomic and compact dashboard for tractor control, proposing an innovative methodology in line with human-centered design and ergonomics principles. The study started by shifting the focus from how a machine works to how a task has to be performed and how the user interacts with the machine. It uses virtual simulations and human performance analysis tools to support the concept generation and the detailed design, and to test the new idea with users in the virtual lab. Indeed, within the virtual environment, different configurations of controls can be tested, checking which controls are mostly used and measuring human performance indexes (i.e., postural comfort and mental workload) for each configuration. Virtual mannequins can be used to as "digital twins" to interact with virtual items and to calculate robust comfort indicators during task execution. The study adopted the proposed methodology to an industrial use case to develop a usable and compact armrest for a new tractor platform. The new armrest is smaller than the previous one (-30% in dimensions), more usable (keeping on board only frequent controls, better positioned), and more comfortable (it satisfies 95% of the population size). This new approach could be used also for the design of new products.

Keywords. Virtual simulation, Human-centered design, Human Factors, Usability

Introduction

Driving and control of agricultural machinery is a stressing activity, physically and mentally. Indeed, the use has to drive and contemporarily also execute a lot of body movements such as steering, looking forward and backward, and also control the vehicle's dashboard, using clutch, brake, control levers [1]. Recently, most tractors' producers have introduced specific dashboards where the majority of commands are located, in order to support the tractor control. However, such dashboards risk being large and invasive, full of controls and not fully adjustable to the users' preferences, as demonstrated by internal market analysis and panel tests with users. It has been also

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proved that an incorrect use of tractor commands in the long term could generate physical health problems in different upper parts of the body (i.e., arms, neck, shoulders, back, head) [2]. As a consequence, the dashboard design, including its position with respect to the seat and other interaction devices, plays an important role in determining the driver's comfort and can significantly enhance operator productivity, comfort and safety [3]. In this context, the adoption of an ergonomic approach is compulsory. It supports the inclusion of human factors in tractor design in order to respond to physical, psychological, social and cultural needs of human beings [4]. As far as industrial system design, the optimization of posture, physical overload, perceived effort, discomfort, and physical fatigue is fundamental to satisfy the users' needs, pre-vent musculoskeletal disorders and stressing conditions [5]. In this context, the analysis of human factors has a central role in the understanding of human behaviours and performance interacting with systems, and the application of that understanding to design of interactions [6].

The paper presents a set of innovative tools to re-design human-centric, ergonomic control dashboards and describes their application to a real industrial case, concerning a specific tractor dashboard re-design. In particular, the research approach integrates different methods for the acquisition of physical and physiological parameters, in order to collect the biomechanical performance of "real" users', and its virtualization within a virtual lab for simulation and testing. Indeed, the virtual environment allows to replicate the "typical" users' behaviour thanks to a "digital twin" and to test many different configurations of controls, by measuring a global comfort index for each design. Such an approach has been really usefully for the re-design the new mini armrest, based on the satisfaction of the users' needs.

1. Research Background

The goal of ergonomics is not only to improve work performance but also to improve human comfort as well as safety [4]. If ergonomic aspects are not given due consideration, the performance of the system will be poor and the effective working time will be reduced. Moreover, ergonomics is a typically a transdisciplinary discipline since it requires technical as well as social-science skills and certainly involves people from practice. Technical science concerns with the design of machines, interfaces and information system. Social science assists in identifying the needs of users in order design usable and useful interfaces and interaction systems. Application of ergonomics to industrial systems is definitely transdisciplinary as it requires multiple disciplines, as well as people from practice, because the problems encountered can be multi-faceted [7].

The best approach to ergonomics is the preventive one, which consists of anticipating ergonomics problems during the design stage in order to optimize the overall system design to conform to the physiological, psychological, and behavioural capabilities of workers. There are many factors acting as stress on the operator during the work. These stresses may be due not only to physical workload and uncomfortable postures, but also to task complexity, overload of information to be handled, time pressure [8]. This fatigue can be measured in terms of strain on the tractor driver [9]. The most common analyses typically include electrocardiography (for heart rate monitoring), electromyography (for monitoring muscles activity through their electrical potentials), the pneumography (for respiration control) or the skin conductivity (to measure sweat activity) [10-11]. The multimodal dimension of stress makes the research field very broad; however, four main criteria can be distinguished in detecting the human stress, according to ISO 10075-3 [12]: psychological, physiological, behavioural, and biochemical. From a physiological point of view, the increase of nervous system activity changes hormone levels in the body and provokes reactions such as sweat production, increased heart rate and muscle activation. Breathing becomes faster and increases blood pressure. Usually skin temperature and HRV fall. The diameter of the pupils can vary. Finally, behavioural reactions include eye movements and eye change rates, as well as changes in facial appearance and head movements.

There are many physiological signals to be used in stress detection and some of them have shown to provide reliable information about peoples' real-time stress levels [13]. Electrocardiogram (ECG) is one of the most used signals in stress detection research because it reflects directly the activity of the heart, mainly the Heart Rate (HR, defined as the number of heart beats per minute), the Heart Rate Variability (HRV, defined as the temporal variation between sequences of consecutive heart beats) and the LF/HF ratio (low frequency / high frequency). Moreover, eye activity in terms of number of gazes and blink rates can be measured with infrared eye tracking systems or with image processing techniques applied to visual spectrum images of the eyes. Thus, pupil dilatation exhibits changes under stress situations and can be measured by the dilation mean value, standard deviation, gaze spatial distribution, number of fixations, as well as the blink rate or blinking frequency.

2. Research Approach

The research approach integrates different tools for the acquisition of physical and physiological parameters in order to objectify the users' experience and workload, as follows:

- Use of sensors for real-time analyses of the main physiological parameters, which can provide a clear feedback on the driver's state without interference with the driver's activities. The adopted sensors refer to: a bio-sensor for electrocardiography (for heart rate (HR) and heart rate variability (HRV) monitoring), breathing monitoring (for breath rate (BR) analysis) (i.e., BH3 by Zephyr) and an eye-tracking device for eyes' fixation analysis and visual attention mapping (i.e., Glasses3 pro by Tobii);
- Motion capture for real-time analyses of body movements, to measure the position of the different body parts (e.g., arms, hands, head) and to objectify the human interaction in terms of distance, joint angles, instantaneous speed or acceleration) (i.e., Xsens MVN by Xsens);
- A human simulation software for virtualization of human-machine interaction and physical ergonomic analysis by Dreyfuss methods (i.e., Jack by Siemens);
- A CAN (Controller Area Network) data collection for analyses of the human inter-action with the control devices and interface, to check whether and what type of interaction is taking place during task execution.

Moreover, the research approach is based on a three-phase experimental study.

Phase 1. First of all, real users are monitored during field tests interacting on the real, physical dashboard using the proposed set of tools, in order to define the typical users' actions and to identify the main critical tasks and the main interaction difficulties. During this phase, a sample of users, representative of the target users of the specific product under investigation, drives a real tractor executing a set of pre-defined activities, and their physiological and physical data are collected by wearable technologies

(BioSensor BH3 and eye-tracking Glass 2). In the meanwhile, interaction data from the CAN network are collected from the tractor itself. This phase allows to define the users' needs and to analyse how commands and controls are used, in order to highlight ergonomic issues and propose a more usable grouping for the new dashboard design.

Phase 2. On the basis of the data collected during Phase 1, different dashboard designs are produced and prototyped. After that, simulation sessions within a Virtual Lab involving users are organized; users are virtualized and a virtual mannequin is associated to each user to create the specific digital twin. Different cabin layouts and dashboards design are simulated and verified on the basis of virtual mannequins generated by tests with users. Virtual mannequins are used to represent different-sized operators, and for each of them to check the visibility, reachability and joint comfort of humans on dashboard proposals.

Phase 3. Finally, the motion capture system (Xsens) is used to track real users' movements during virtual testing in Lab and emulate the human-machine interaction within an immersive environment. The immersive simulation is useful to evaluate he interaction with the final dashboard layout and to validate it by expert-based assessment. Moreover, motion capture allows to create more reliable digital twins of real users, and to effectively measure the joint angles and comfort indexes. Real missions can be simulated and the new dashboard design validated in the virtual environment.

Fig.1 shows the adopted tools and the data elaboration framework.

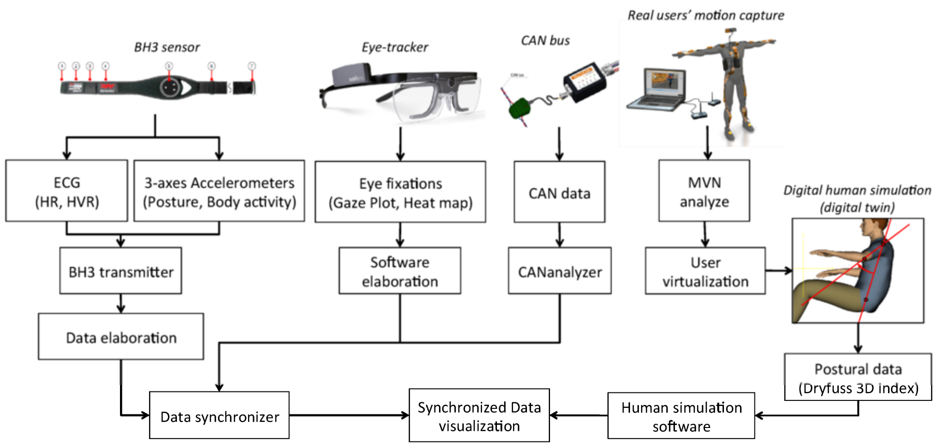

Figure 1. The research data elaboration framework.

3. Experimental testing on the industrial use case

3.1. The industrial use case

The use case focuses on the Steyr brand, in particular on the re-design of the control dashboard of the Expert CVT model. This tractor is aimed at customers who need high performance tractor with compact dimensions and high comfort. This model is presented on the market for its particular ergonomic character and its multi-controller armrest able to merge comfort, flexibility and high-quality performance. Indeed, its cabin is characterized by smaller dimensions (minor length and width with respect to other Steyr models), lower intrusiveness for the operator trunk-legs, and improved sensation of roominess inside the cabin. Moreover, it has an innovative controls layout, with many controls managed with push-buttons, grouped in a more organized-intuitive way using different panels to help operators to immediately find each control. Both characteristics improve the human comfort during working in a tractor cabin and reduce the mental workload.

The proposed approach was applied for the re-design of the Expert CVT armrest. For Phase 1, five "typical" users were selected and involved in on-field testing. It was useful to map the users' behaviours and needs. After that, Phase 2 was oriented to link the virtual mannequins belonged to different percentiles (5p, 50p and 95p) were used to represent different-sized operators, and for each of them to check the visibility, reachability and joint comfort of humans on cabin armrest proposals. Many proposals were investigated, especially to find out the good compromise between reduced dimension of the armrest and a visible and effective control layout to be operated in comfort for different human percentiles. Fig. 2 shows the virtual prototype of the Steyr Expert CVT armrest and examples of virtual tests with mannequins belonged to different percentiles (5p, 50p and 95p). Fig. 3 shows examples of virtual testing about reachability and visibility.

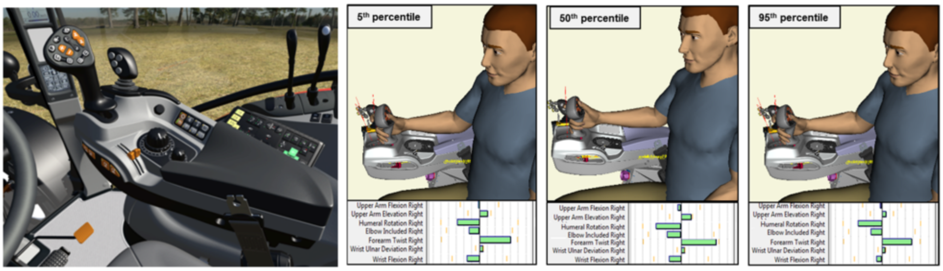

Figure 2. Virtual prototype of the Steyr Expert CVT armrest (left) and virtual tests on different percentiles - 5p, 50p and 95p (right).

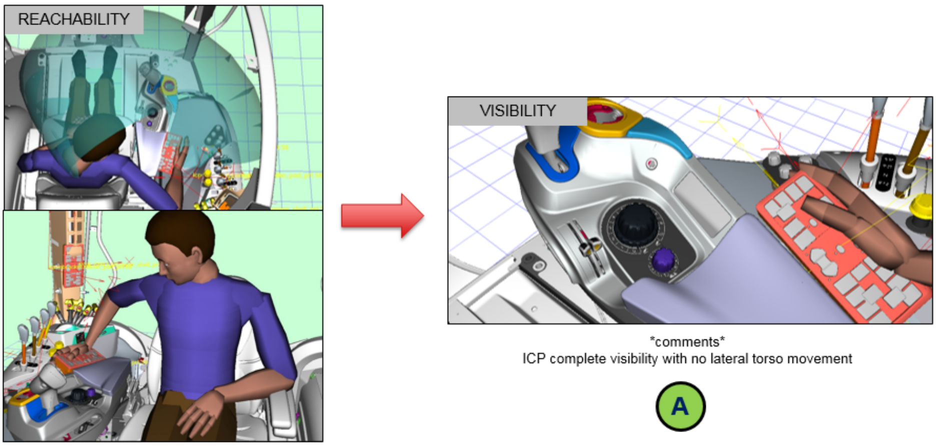

Figure 3. Examples of virtual testing checking reachability and visibility on different layouts.

After that, a new armrest was designed to improve the user comfort and armrest usability. Finally, Phase 3 focuses on the simulation in Virtual Lab using the motion capture and real users' involvement to check the interaction modalities and improved performance. Fig. 4 shows the new armrest layout and immersive testing in Virtual Lab.

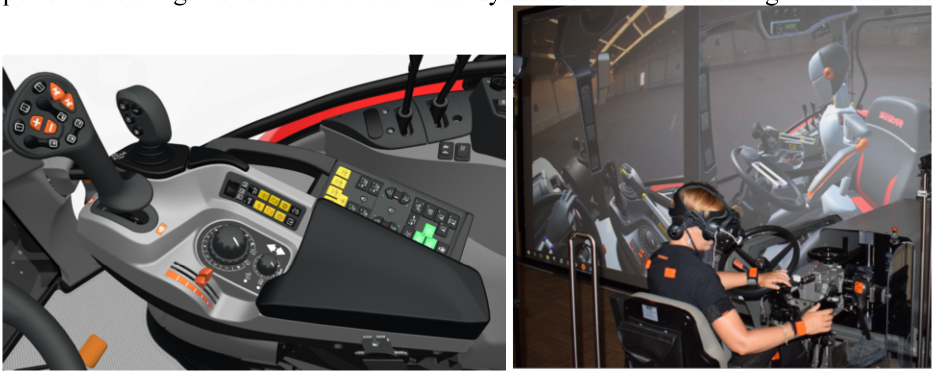

Figure 4. New armrest layout based on intuitive-grouped control panels (left) and immersive tests in Virtual Lab (right).

3.2. Results and discussion

During experimental testing, data about the user physiological and physical state were collected and correlated with the interface use and the visual interaction quality. After that, data synthesis and post-processing allowed analysing the user workload in order to understand the level of comfort and the usability of the armrest, considering also the level of stress and the perceived quality of interaction. The main advantages of the proposed approach are the use of virtual users during the design phases, in order to validate different design solutions, and the limitation of the involvement of real users only to the last phase. Immersive virtual simulation allowed creating a digital environment where users can interact in advance with the product features, to address the main interaction criticalities during the design stage. Predictive analysis can be carried out before real product realization, and an optimized product was created, avoiding late optimization actions. Indeed, the use of digital simulations allowed easily comparing different product layouts, replicating the sequence of actions, predicting the user movements, and defining the best design solution.

The main results obtained by the new armrest design are:

- Higher comfort index for all users, and in particular for taller users (95p) as demonstrated by the Abita4t maps toolkit. Fig. 5a highlights how 5p, 50p and 95p manikins can comfortably accommodate in the new armrest cushion, using all armrest possible adjustments (all green boxes, higher than 75%). Fig. 5b shows seat comfort maps;
- Reduced encumbrance (the new armrest is 20% shorter and 30% thinner than the previous one). Fig. 6 shows its main dimensions and compared it with the previous armrest;
- Higher performance and reduced time for tractor control due to an optimized control layout with push button panels (indeed, the new armrest allows keeping on board only frequent controls positioned in ergonomic way).

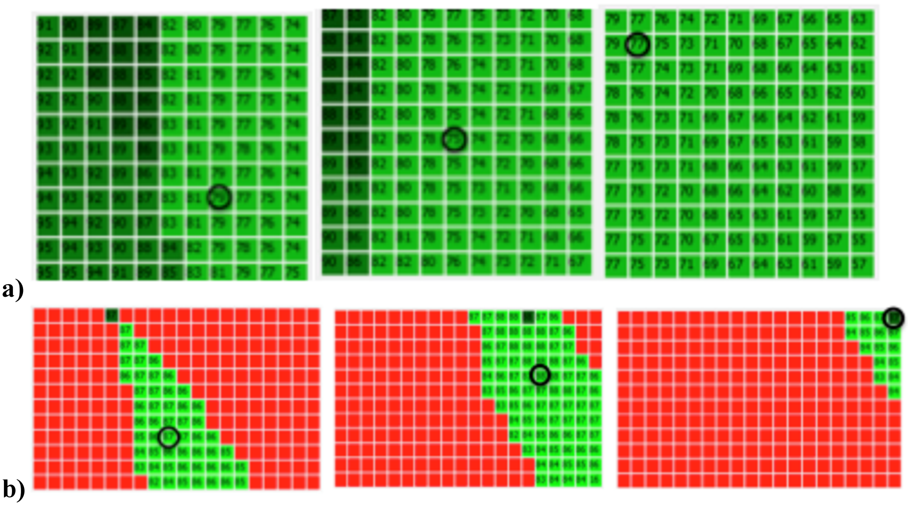

Figure 5. Comfort indices (a) and seat maps comfort indices (b) for the new armrest design (5p, 50p, 95p).

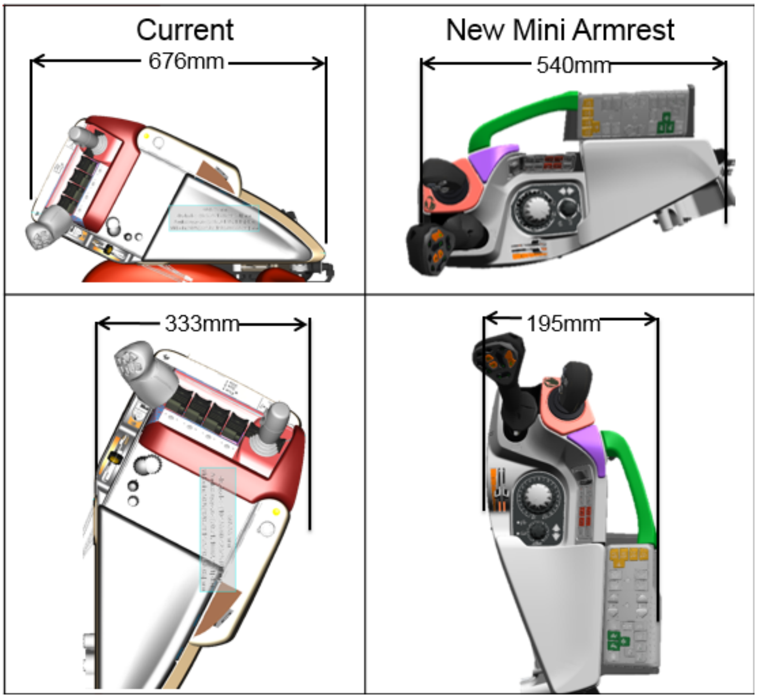

Figure 6. Dimension comparison between the previous armrest and new compact-ergonomic armrests.

4. Conclusions

This paper presented a set of innovative tools to support ergonomic, human-centered design of control dashboards and described its application to the re-design of control board of tractors, in collaboration with CNH Industrial. The new approach combines digital technologies, virtual reality and human monitoring devices to objectify the user experience and to introduce ergonomics validation before product realization. The new approach allowed to reduce re-design time, to reduce the final product costs, and to improve the user comfort as well as dashboard usability. In particular, the new armrest is smaller than the previous one (-30% in dimensions), more usable (keeping on board only frequent controls, better positioned), and more comfortable (it satisfies 95% of the population size). Such results could be used also to guide the re-design for other tractors controls and dashboards, so that human comfort can be improved and any task can be felt as natural as possible, encouraging good posture and safe behaviours, and reducing cost of prototypes and time to market. From a societal viewpoint, the inclusion of human factors in systems design can overcome the current issues due to changes in technologies and requirements of workers, and enhance their work conditions. The proposed methodology merges different disciplines in order to assess the general comfort of the user, according to a transdisciplinary approach.

Acknowledgement

The authors wish to acknowledge CNH Industrial staff for the precious collaboration.

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Humanization and Macroergonomics: An Analysis in the Billing Sector of a University Hospital in Paraná

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Abstract. The humanization of organizations is a trend in companies that have a vision of the future aligned with the needs of the market. In the health area, this humanization should not be limited to its users, but include the employees involved in the work system. The human aspect and its relations with the work system is a focus of studying ergonomics, which in its macroergomic approach aims at integrating organization-man-machine systems into a sociotechnical and participatory context. This study aims to apply the macroergonomic approach with health workers in order to propose and implement improvements; evidencing the importance of their involvement in better acceptance of the proposed improvements generating greater satisfaction. To this end, a study was conducted in the Billing sector of a Brazilian Hospital. Ergonomic demands were identified in a participatory way through the Macroergonomic Analysis of Work (MAW) method, proposed in [1]. The results were tabulated and divided into constructs: Environment, Biomechanical, Cognitive, Work Organization, Risk, Company and Discomfort/Pain. After one year, a new macroergonomic evaluation was carried out and the improvements implemented included the concept of the sociotechnical system, which were: i) acquisition of new computers; ii) implementation of a new computational system and; iii) implementation of changes in the form of sector management. The results showed an increase of up to 40% in satisfaction with the improvements implemented in the Biomechanical and Organizational constructs, indicating that the application of participatory ergonomics and macroergonomics was fundamental for the changes made to increase satisfaction in aspects of the work performed by them. Finally, this research highlights the importance of employee involvement in sociotechnical analysis for the humanization of organizations and it is suggested for future studies the proposition of improvements related to the Environment and Cognitive constructs and pain/discomforts.

Keywords. Humanization; Ergonomics; Macroergonomics; Improvements; Satisfaction.

Introduction

In the organizational context, the humanistic approach of administration aims at the care, integration and harmonization of different stakeholders, based on philosophical humanism, considering workers as individuals and as people who relate to the work environment [2]. Similarly, ergonomics is a scientific discipline that aims to optimize human well-being and the overall performance of the work system, based on human interactions with other elements that make up a work system [3]. In its macroergonomic approach, ergonomics consider the worker's participation in the integration of

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organization-man-machine systems [1]. Therefore, despite being disciplines of different areas of study, both focus on the study of the human and their relationships in the work environment.

Collaboration between disciplines from different areas in order to solve unstructured problems is part of the transdiciplinary research process [4]. The research of transdisciplinary engineering uses not only disciplines from engineering (as is the case of ergonomics), but also of disciplines from other areas, aiming at solving problems making use of profissional of various specialties and stakeholders [5].

Thus, considered for the realization of this study the participation of workers as a central point for humanization and macroergonomics in the context of the billing sector of University Hospital located in the city of Curitiba in the state of Paraná in Brasil.

The departament in question is responsible for detailing all the costs that the hospital obtained with the treatment of its patients within the conformities stipulated by the Brazilian health system. The billing department must follow the payment pattern stipulated by the public health system in Brazil, so that the hospital receives funds for the continuous treatment of patients. The challenge for the billing sector is to align the costs of maintaining the hospital with the value provided by the Health System. In view of this, the sector is constantly under pressure to improve its work processes and the performance of its workers, so that all the necessary value for the maintenance of the hospital is provided by the Health System.

Therefore, this study aims to apply the macroergonomic approach with a view to humanizing the environment of health workers in order to propose and implement improvements; evidencing the importance of their involvement in better acceptance of the proposed improvements generating greater satisfaction.

The article is organized as follows, in section 1, the definitions of humanization, ergonomics and macroergonomic are described. Section 2 presents the methodology used in the study. Section 3 presents and discussed the results of the study. Finally, section 4 contains conclusions and suggestions for future studies.

1. Background

This section presents a humanization briefing (section 1.1) and the description of the concepts related to ergonomics (section 1.2), the two disciplines considered in this study.

1.1. Humanism

Humanism is a guiding perspective on human needs and oriented towards the development of human virtue. Concerns about the structuring of social life based on human characteristics, assuming that everyone has the same rights and must reach everyone [6] [7].

Humanistic organizations are guided by humanistic concepts, such as social group, group dynamics, motivation, communication, leadership, teamwork, seeking to develop individual motivations of employees and reduce gaps between the organizational and individual objectives of employees. These organizations promote the integration between the objectives of different stakeholders, promoting the balance of qualitatively desirable results [8] [7].

The humanistic approach of the Administration is ruled in a more democratic and humanized organizational administration, which does not block individual growth and self-development of workers, emphasizing the human condition in work [8] [6].

1.2. Ergonomics

According to [9], "Ergonomics (or human factors) is the scientific discipline concerned with the understanding of interactions among humans and other elements of a system". Its objective being the optimization of human well-being and the overall performance of the system [3].

The study of ergonomics is formed by the man-machine-environment system, being the man any person, or people, responsible for performing a work; the machine, and can be both physical and cognitive; and the environment, which can be internal, where the work takes place, or external [10].

Ergonomics in its man-system interface technology consists of five interfaces, including man-machine interface or *hardware*-ergonomics, human-environment interface or environmental ergonomics, human interface-software or cognitive ergonomics, man-work interface or ergonomics of work design and, organizational ergonomics or macroergonomics [11].

Macroergonomics is the ergonomic approach that considers the man-organization relationship and external factors that influence this relationship, and therefore is the most comprehensive of its approaches.

1.2.1. Macroergonomics

Macroergonomics, defined by Hendrick, works in order to integrate the organization-man-machine systems. This approach considers the human factor within the organization and external factors that influence its work, encompassing socio-technical characteristics of the organization, considering characteristics of the work system, external system and personal system. It makes use in its application of participatory ergonomics, providing with the involvement of employees to improve productivity, increased satisfaction, improvement in safety at work and in the company, causing reduction of errors and accidents [12] [10].

Based on the application of the concepts of humanization and ergonomics, this article proposes the use of worker participation as a central point in the application of humanization and macroergonomics in order to propose and implement improvements in the study sector, increasing worker satisfaction.

2. Methodology

The study is based on the billing sector of a University Hospital in the city of Curitiba – Paraná, Brazil, in which two samples of 17 employees participated in the study, corresponding to 89% of the total number of employees in the departament, in 2018 and 2019. In this case study, information is collected and analyzed and worked qualitatively and quantitatively in order to apply the MAW method.

2.1. Macroergonomic Analysis of Work (MAW)

The Method of Macroergonomic Analysis of Work (MAW) was proposed by [1] to identify, monitor and modify participatory any activity that puts at risk the quality of life of the worker. With the application of MAW, we have an analysis of the work both from the point of view of the ergonomics (specialist responsible for the application of ergonomics) and of workers, who participate directly or indirectly.

The method consists of six stages, which are iterative and not necessarily linear, being: 0 - project launch, 1 - ergonomic survey or appreciation, 2 - ergonomic diagnosis or situation analysis, 3 - proposal of improvement solutions, 4 - validation solutions and 5 - ergonomic detail [1]. Phase 5 was not contemplated in this study.

2.1.1. Project launch

As a way of launching the project, a meeting was held with the board of the hospital in which the macroergonomic analysis of the work was agreed.

2.1.2. Ergonomic appreciation and diagnosis

To survey the ergonomic demands of the billing sector, an interview was conducted spontaneously and voluntarily with a convenience sample of 7 employees. Based on results obtained with the interviews, direct observation of employees in their work post and in the opinion of an ergonomics specialist, satisfaction, importance and discomfort/pain questionnaires were elaborated.

The questionnaires were composed of questions regarding the Environment, Biomechanical, Cognitive, Work Organization, Risk and Enterprise (EBCORE), and discomfort/pain, and the answers were given through a continuous line.

This method uses questions in its questionnaires with a continuous line of 15 cm so that respondents mark an x at the location of the line they think is most correct for the question. At the ends of each line are words that guide the formation of a continuous scale. At the left end, indicating the value zero, are the words unsatisfied, unimportant or low, with each word used in the satisfaction, importance and discomfort/pain questionnaires, respectively. At the right end, there are the words satisfied, important and very much, with each word used in the satisfaction, importance and discomfort/pain questionnaires, respectively [13].

The scale indicates that the closer the answer is to 0 cm, the less satisfied, the less important or the lower the score for the corresponding question requirement. Whereas, the closer the answer is to 15cm, the more satisfied, the more important or higher the grade for the requirement of the question corresponding to the answer. The 7.5cm indicates the average value.

With the help of the Software SPSS® version 22.0.0.0, the Cronbach Alpha test was performed for all constructs, aiming to analyze the consistency of the data obtained with the answers of the questionnaires, obtaining a value of 0.805, characterizing in a high reliability of the data.

Graphs were sketched using Microsoft Excel Software® version 1804 referring to EBCORE constructs, considering the average values of each question for importance, satisfaction and pain.

Cluster analysis (partitioning of a dataset into smaller subgroups that are significant) was performed through simulations with the aid of Minitab Software® version 17.1.0, in order to identify the type of link that best represents the concepts of the study through the form of a dendogram [14].

2.1.3. Proposals and validation of improvement solutions

Based on the results obtained in the graphs and cluster analysis, it was possible to perform analysis of the data obtained with the interviews, to make the diagnosis of demands and thus the proposals for improvements. The proposals for improvements were presented to the hospital board in order to promote its validations and applications. [15] represented in detail the methodologies for implementing steps 0, 1, 2, 3 and 4 and their respective results.

2.1.4. Ergonomic diagnosis

Because it is an iterative method that allows reassessments at any time, it was recommended to reevaluate the perception of employees in the sector regarding the proposed improvements. After one year of the applications of steps from 0 to 4, the discomfort/pain questionnaires and satisfaction in relation to the EBCORE constructs were reapplied. The data obtained with the application of the questionnaires also obtained some consistency, with a value of 0.663, but this consistency for being below the value 0.7, indicates that the data obtained from the questionnaires are not as reliable as those of the previous year.

3. Results

3.1. Participation: a focal point

Because it is a sector highly pressured in the search for performance improvement, it was necessary to evaluate, from the point of view of workers, how impactful the changes made in the hospital affected the way work is performed. Participation, then, was not fundamental for this evaluation. The reapplication of step 2 of the MAW method through satisfaction and discomfort/pain questionnaires and the comparison between the values of the 2018 and 2019 EDIs (Ergonomic Demand Index) were ways to perform a humanistic management of the sector and validate the modifications.

3.2. Proposition and application of solutions

In his 2018 study, [15] performed ergonomic appreciation and diagnosis (stages 1 and 2 of the MAW) of the sector, presenting data obtained with the performance of interviews with employees for the construction of The EDIs in the applications of the questionnaires of satisfaction and discomfort/pain and, later, being carried out in-depth analyses based on statistical techniques and references in the area of Ergonomics. Based on the analysis, suggestions for improvements to the sector were proposed and the direction of the hospital was presented.

In 2019, the hospital underwent management changes, changes that affected the way work was carried out in the Billing sector. Thus, after the implementation of the changes, satisfaction questionnaires and discomfort/pain were applied in order to identify possible improvements in The EDIs.

3.2.1. Comparison of satisfaction between the years 2018 and 2019

The changes that occurred in the hospital generated three changes for the sector, which were: i) acquisition of new computers; ii) implementation of a new computational system and; iii) implementation of changes in the form of sector management.

i) Acquisition of new computers: new computers were purchased that were compatible, in terms of processing, to programs that are utillized by the sector for account billing;

ii) Implementation of a new computational system: in addition to the systems offered by the Brazilian health system, the hospital uses an internal system. The internal hospital system was exchanged for one that integrated the various areas of the hospital;

iii) Implementation of changes in the form of sector management: with the change of management of the hospital, the management of the sector, which was previously made by the financial area, passed to be carried out by the quality area of the hospital.

In the satisfaction questionnaires applied in both years, values were considered on a scale between 0, which considers the total unsatisfaction of the employee in relation to the EDI, to 15, which considers the total satisfaction of the employee in relation to the EDI. EDIs that obtained average responses from employees with values below 7.5 would be considered for EDIs that deserved attention. In 2018, EDIs that obtained low averages were the target of possible improvement proposals and, in 2019, they were analyzed if the improvements made in the previous year affected EDIs that needed attention.

For questionnaires referring to the Cognitive construct in both years, values (or equals) to 0 considered less and values close (or equal) to 15 considered very much. Averages below 7.5 are not necessarily considered bad and EDIs are worthy of attention, with each EDI in particular to understand the average below 7.5 is positive or negative for the EDI.

Table 1 presents the mean values of the EDIs for the EBCORE constructs, with the data of [1] for 2018. Note that the satisfaction of employees regarding several EDIs had changes in values, due to the changes made, and the amount of EDIs with averages below 7.5 decreased. The constructs Biomechanical, Cognitive and Work Oganization present greater differences in their values of means, and the Cognitive construct detailed in 3.2.1.2.

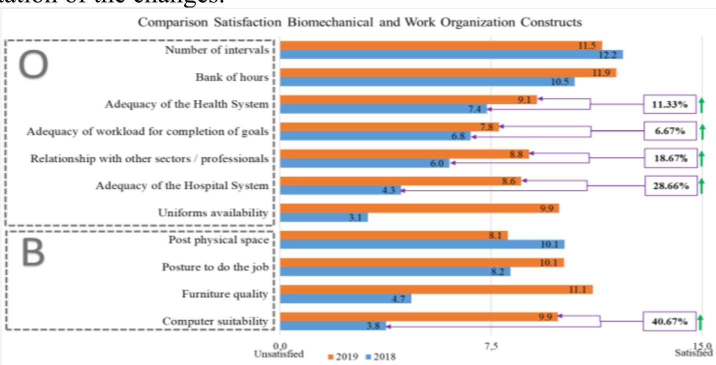
Table 1. EDIs averages per construct for the years 2018 and 2019.

Costruct	EDI	Average EDI 2018	Average EDI 2019
Environment	Temperature	5.9	6.3
	Air quality	5.8	9.5
	Cleaning quality	6.0	5.1
	Noise	7.0	7.2
	Lighting	6.1	6.2
Biomechanical	Post physical space	10.1	8.1
	Posture to do the job	8.2	10.1
	Furniture quality	4.7	11.1
	Computer suitability	3.8	9.9
Cognitive	Physical effort	5.8	5.4
	Mental effort	14.2	123
	Monotonous work	5.5	8.6
	Limited work	6.1	9.4
	Creative work	6.6	5.0
	Dynamic work	9.6	5.7
	Stimulating work	8.7	7.1
	Complex work	12.8	11,6
	Repetitive work	10.7	12.5
	Tiring work	12.8	1,9
	Work involves responsibility	13.9	13.7
	Appreciation for work	9.7	9.4
	Autonomy at work	11.1	9.2
	Stressful work	12.3	11.3
	Psychological pressure by superiors	8.9	7.5
	Feels safety at work	8.4	9.3

	Like work	13.0	12.3
	Workload	12.3	10.8
Work Organization	Number of intervals	12.2	11.5
	Adequacy of the Hospital System	4.3	8.6
	Adequacy of the Health System	7.4	9.1
	Computer adequacy	3.8	9.9
	Uniforms availability	3.1	9.9
	Relationship with other sectors/professionals	6.0	8.8
	Bank of hours	10.5	11.9
	Adequacy of workload to completion of goals	6.8	7.8
Risk, Company	Transportation to work	10.1	8.9
	Salaries and other policies	6.6	7.8
	Trust that the company transmits	8.9	9.7
	Benefits achieved by achieving goals	6.8	4.1

3.2.1.1. Satisfaction in Biomechanical constructs and Work Organization

As presented in Table 1, the Biomechancical and Work Organization constructs had significant variations in the averages of their EDI between 2018 and 2019. Thus, Graph 1 presents the percentage difference between the two years of application of satisfaction questionnaires, highlighting the changes that occurred in the sector due to the implementation of the changes.



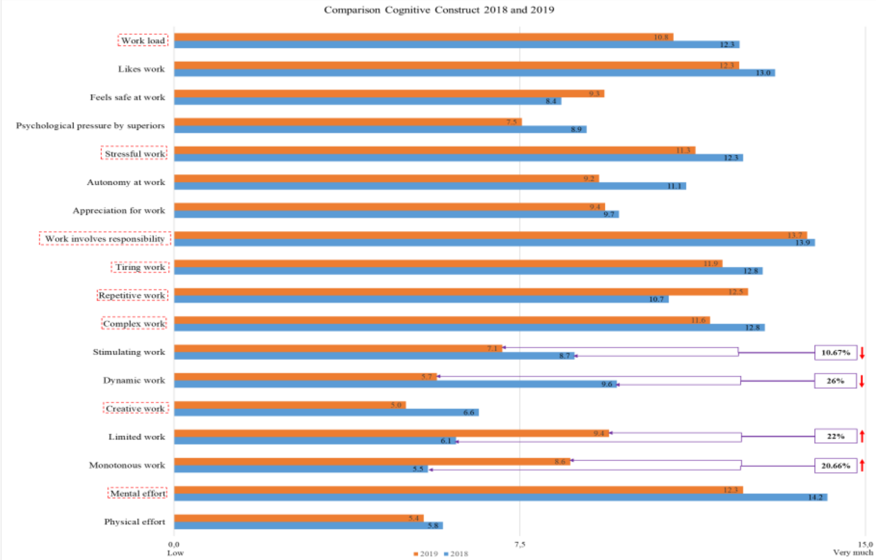
Graph 1. Comparing stisfaction to the Biomechanical and Work Organization for the years 2018 and 2019.

From Graph 1, it is pointed out that the satisfaction regarding the computer suitability is the one that obtained the most significant improvement, with a 40.67% difference in their satisfaction. Next, there is a difference of 28.66% in the satisfaction of the adequacy of the Hospital System, with the exchange of the system used internally in the hospital. Satisfaction in relation to the relationship with other sectors/professionals obtained a difference of 18.67% and, 11.33% difference in the adequacy of the Health System, this reflection of the exchange of computers for more appropriate use. Finally, the adequacy of the workload for completion of goals obtained a difference of 6.67% in satisfaction, indicating that the changes in computers and in the system used by the hospital reflected so that the time to complete the goals became more appropriate, thus increasing satisfaction. Thus, Graph 1 reflects the opinion of employees that with the changes made to satisfaction and performance during the work performed by them, they increased.

3.2.1.2. Opinion in the Cognitive construct

The analysis of the difference in opinion of workers regarding the Cognitive construct becomes necessary, since the averages of the EDIs suffered variations between 2018 and

2019. Cognitive requirements in workers have increased due to changes in work [16], as occurs in the present study. To understand how the way workers see their work was modified by the changes, The Graph 2 was elaborated.



Graph 2. Comparison of opinion for the Cognitive construct for the years 2018 and 2019.

Graph 2 points out the percentage difference between the opinions of the workers about the EDIs of this construct. Between 2018 and 2019 some EDIs deserve attention and require an in-depth investigation for the difference found, they are dynamic work, stimulating work, limited work and monotonous work.

Comparing the averages of the EDI dynamic work, it is noted that between 2018 and 2019 employees began to consider the work much less dynamic, from an average of 9.6 in 2018 to an average of 5.7 in 2019. For the EDI stimulating work, there was a reduction of 10.67% in how stimulating employees consider the work, requiring a deepening of the reason that caused the change of stimulus in the work developed by employees. In 2018 the collaborations considered the work much less limited, with an average of 6.1, but in 2019 the average for this EDI increased, becoming 9.4, a difference of 22% that also deserves an in-depth investigation.

According to [10], works that are very repetitive and with prolonged activities end up being unmotivating and monotonous, so the work developed by employees in the sector can be considered monotonous. Although in 2018 employees did not consider the monotonous work, an average of 5.5, however, in 2019 the work began to be considered monotonous, with an average of 8.6, pointing to a difference of 20.66% in monotony. Thus, it is necessary to evaluate what workers understand by monotony.

In both years the work involves a lot of responsibility and great psychological pressure by superiors because all patient data should be thoroughly evaluated so that there are no errors in the accountability of the hospital. In addition, there is a lot of mental effort in both years, because it requires a lot of attention from employees and a high work load per employee, because the hospital serves large volume patients daily, so there are a large amount of bills to be billed by the sector and established by the Health System to be achieved.

For both years, the work is considered complex and tiring, involving high responsibility related to the billing of hospital accounts, the work becomes stressful, because it requires a lot of mental effort from employees in the sector. In addition, in both years, employees have low autonomy and consequently work becomes more limited and less dynamic.

3.2.2. Comparison Discomfort/Pain in the years 2018 and 2019

Another analysis was related to Discomfort/Pain of employees, in order to point out possible relationships between the way the work was developed in 2018 and differences in the perception of workers after the changes made in the sector. For questionnaires related to Discomfort/Pain, values (or equals) to 0 considered low and values close (or equal) to 15 considered too much (very much), being for average responses greather than 7.5 indicative of EDIs that deserves attention, because they represent immediate intervention pains. Thus, similarly to that presented earlier, Table 2 was elaborated, which presents the means Discomforts/Pains for the years 2018 and 2019.

Table 2. Averages of Discomfort/Pain EDIs for the years 2018 and 2019.

Discomfort/Pain	Average EDI 2018	Average EDI 2019
Arms	6.7	8.4
Hands	8.3	7.8
Legs	6.6	7.3
Feet	5.5	5.9
Back	10.0	10.2
Neck	10.3	9.6
Head	10.0	9.5
Stomach	5.5	4.7

According to the data presented in Table 2, it is pointed out that the worst Discomforts/Pains are in the back, neck, head and hands both in 2018 and in 2019. These four Discomforts/Pains have averages above 7.5 and should be considered for short-term intervention. Also, for 2019, pain/discomfort in the arms also has an average above 7.5. Studies such as [17] indicate that musculoskeletal pain may be associated with stressful work, as also pointed out in this study.

4. Conclusions

This transdisciplinary study is a collaboration between the disciplines of management (humanism) and ergonomics (in its macroergonomics approach). A study is conducted with billing staff at the University Hospital in the city of Curitiba – Paraná, Brazil, they are evaluated before and after changes in their workplace are implemented.

The participation of employees in the billing sector of a University Hospital in Brazil was the focus of the joint application of the macroergonomic approach and humanization. With the participation of employees, it became possible to find the requirements that needed improvement and thus, with their improvement, increase worker satisfaction.The use of the MAW participatory method helped to deepen workers' perceptions of the work they perform and in the identification of ergonomic demand indexes that lacked, and some still lack, improvements. MAW was fundamental for a diagnosis of the problems found in the sector, besides assisting in the identification and implementation of improvements.

From the results found, there was a 40.67% improvement in satisfaction with the computers suitability, as the new computers are more suitable for the activities carried out in the sector. There was also a 28.66% increase in workers' satisfaction with the change of the system used by the hospital. In addition to an 18.67% increase in the satisfaction of professionals in their relationship with other sectors / professionals, due to the change in the sector's management area.

The results of the two years indicate that workers in the sector have a high work load, are highly stressed, have a lot of responsibility, are highly tired, perform very repetitive and highly complex activities. The work done by the workers is considered to be not very creative and requires a lot of mental effort. In addition, in 2019, workers began to find work less stimulating, with a 10.67% reduction in this requirement compared to the previous year.

The results for the year 2019 also indicated that workers started to consider work much less dynamic (with a reduction of 26% compared to 2018) and much more limited (with an increase 22% compared to 2018). The term monotony is not understood by employees in 2018, but it started to be understood in 2019 after the changes made, since the difference between the two years is significant, of 20.66%.

Finally, it is suggested that in future work the way the work process of the sector is conceived be evaluated, in order to make it less stressful, tiring, complex, repetitive, limited and monotonous, requiring less responsibility and psychological pressure on the part of the superiors, and thus more dynamic, creative and stimulating for workers, reducing their musculoskeletal pains (hands, arms, neck and back) and head. Also, it is suggested that other ergonomic evaluation methods be applied in order to solve the ergonomic demand indexes of the Environment construct and the physical space for work.

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Sociotechnical System Analysis for Identification of the Informational Requirements of Prosthetic Device Users for Upper Limb

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Abstract. According to the World Health Organization, more than one billion people on the planet have a type of disability. In Brazil, it corresponds to twenty- four per cent of the population, which creates a high level of social impacts, psychological vulnerability and dependence on others. In this context, Assistive Technology, including prosthetic devices, it is a resource that can be used in order to reduce those vulnerability levels. However, the product market of Assistive Technology is still limited, the few available products present high cost - contradicting Brazil's high poverty levels, and the rates of dissatisfaction and abandonment of those products are quite high since these people have many specificities. Considering these aspects, the Integrated Product Development Process (IPDP) for Assistive Technology arises as a solution to design products that can match the expectations of the users. The main purpose is to present a fraction of the IPDP of a prosthetic device for the upper limb. It is a research of Informational Design which is applied tools of ergonomics and universal design. In the methodology, the social context of people with upper limb disability was investigated applying tools of Macroergonomics, such as Socio-technical System analysis to reach the personal context of users of prosthetic devices. Then, the Likert tool was applied to the collected data. In the results, the user's specificities were found in order to use them to the product's requirements, which ones can contribute to the design of the product. It is concluded that the tools of product development, ergonomics, Universal Design and sociotechnical system analysis have applicability in the IPDP since they enable us to study the specificities of users in order to apply them in subsequent phases of IPDP with the approach in Design for Assistive Technology which contribute to product safety and quality.

Keywords. Design for Assistive Technology; Prosthetic Device, Integrated Product Development Process; Macroergonomics, Socio-technical System

Introduction

The World Health Organization (WHO) claims that physical, cognitive and sensorial disabilities affect more than one billion of people in the world and about one hundred and ten million of them have significative functional impairments that may limit the performance of daily activities and diminish social and economic participation in

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comparison to people without disabilities [1]. In Brazil, about 24% of the population presents at least one type of disability [2]. This situation creates high rates of physical, sensory or cognitive limitation. Besides that, it is an underdeveloped nation highlighting the situation of poverty and cases of social vulnerability of the population [3], in which many no longer have access to support products of assistive technology. Besides, the select group of individuals who manage to acquire have high levels of dissatisfaction and abandonment of assistive technology (AT) equipment, considering that the PwD has personalized specificities and requirements [4].

Through the use of Assistive Technology, it is possible to realize activities promoting quality of life and independence of PwD [4,5]. These AT products or services contribute to the expansion of physical and functional abilities and collaborate with autonomy development of PwD, reducing the social vulnerability rates. Among them, there are the prosthetic devices, the object of this study.

Companies in the AT market must pay attention to the topics mentioned before in order to achieve success in product development [6,7]. Thus, the corporations that use design tools during the development of manufacturing are highly competitive in the market. One of them is the Integrated Product Development Process (IPDP) [4]. IPDP is a set of approaches, methodologies and tools that aim to achieve the development of a product or service of quality in the shortest time possible, considering the necessities of the market, specifications of the project and technological possibilities [8].

This design tool can be divided into phases. One of them is the Informational Design which is responsible for extracting the user's requirements in order to convert them into AT product exigencies [8, 9,10]. In this stage, several methodologies and resources can be used, such as tools of macroergonomics, a transdisciplinary approach [11,12]. One of those tools is the sociotechnical system analysis. The sociotechnical system was applied in this study aiming to comprehend human interactions with AT devices in order to find the users' specific data [13].

Furthermore, IPDP presents two factors that guarantee to develop a product of higher quality with a greater value for the user; therefore, with a minimum level of rejection. They are a) the possibility of including numerous professionals from different areas during the project planning who develop tests, studies, clinical trials, research and applications simultaneously, involving teams with interdisciplinary practice, considering that involves data exchanging in order to develop the product [11,12] and; b) enabling simultaneous application of each phase of the IPDP [8]. The effective application of these two points allows a process of transdisciplinarity during the development of a product [14].

The main objective of this study is to present a fraction of Integrated Product Development Process (IPDP), in which macroergonomics tools are applied with an emphasis on the analysis of a sociotechnical system, Universal Design, Usability in an integrated process of transdisciplinary design. The research was limited to the phase of Informational Design geared towards Conceptual Design of a prosthetic support device for upper limb oriented to daily activities. For this, a bibliography review on the main themes of the study was carried out, followed by a survey through observational and exploratory research in public events where users of assistive technology products participate. Posteriorly, a survey was realized with the data from a sociotechnical system of a group compounded by one hundred and thirty users of prosthetic devices for upper limb, applied by an institution which is a support network for the person with physical disability of limb agenesis. Based on the investigation, a Likert tool [15] was used for data analysis. Finally, in the analysis of the results, the users' specificities have been identified and directed to the products' requirement and are presented in the conclusion of the research.

1. Background

1.1. Assistive Technology User: person with agenesis of the upper limb

In Brazil, PwD totalizes almost a quarter of the population, approximately 45,6 million people. Of these, people with physical disability sum 7% of the Brazilian population, representing about 13,4 million people [2]. Among this disability, there is a group of people with limb agenesis [17]. It is registered, per year, only in Brazilian territory, almost 50 thousand cases. The target audiences of the product development process that this research belongs are:

a) people with upper limb agenesis – concerning congenital malformations, deformities and chromosomal abnormalities during the gestation period and that resulted in the total or partial loss of the upper limbs [18], representing about 202 cases per year in the country [19];

b) population who, by consequence of an accident, trauma or illness, has had their arms, fingers or hands amputated, especially in traffic accidents [18,19]. In the case a, this type of disability affects over two per cent of born-alive children, and a tenth of them in upper's limbs [20].

These individuals pass through daily challenges to be able to perform everyday tasks, such as eating and dressing alone [21]. The area of human knowledge that holds the resources to develop functional skills of PwD, Assistive Technology [5], presents prosthesis of upper limbs, as an alternative solution to these individuals in order to reduce physical limitations and assist in daily life activities [22].

However, despite technological advances, it is still a challenge to develop them in ways that meet the real needs of the users. Thus, some prosthesis of the market does not establish a process of rehabilitation based on these products; therefore, without improving people's quality of life. Consequently, there is a high rate of prosthesis abandonment [6,21].

However the usage of a prosthetic device for the upper limb with the accompaniment of a rehabilitation program provides [9,19,23,24]: a) reduction of muscular dystrophy of the upper limb with agenesis; b) bilaterality exercises; c) strengthening and flexibility in the articulation of the limbs; d) preparation for future definitive prosthetization; c) prevention of scoliosis in adulthood. Finally, the prosthetic device contributes to the autonomy and independence of the person with disability and promotes social inclusion.

1.2. Integrated Product Development Process and Design for Assistive Technology

Engineering continually evolves in the area of Product Development Process. In the 1980s, out of the need to reduce the time for the development of manufacturing and the necessity to understand the new profile of the user, companies developed approaches to conducting faster and more efficient processes. That way, in Concurrent Engineering environments, it reduces the distance between design and manufacture, through tools such as Design for Manufacturing and Design for Assembly, reducing deadlines in product development [25].

IPDP starts from the same legacy in Concurrent Engineering, the parallelism of tasks and presents two factors that strengthen the success of a product: a) the perception more focused on the user and b) transdisciplinarity [8]. The first one avoids professionals to weave a biased idea and guarantee the pleasantness of the users. Thus, from the understanding of the real users' needs, a product that responds directly to the needs of the market is developed [8,26]. Given the collaboration of professionals from different areas, it results in a transdisciplinary and integrated knowledge to develop the IPDP of Assistive Technology. In this way, it is possible to execute the stages of the process more assertively and to develop solutions that are required, considering the insertion of methodologies, approaches and tools from other areas in Engineering and integrating all knowledge of human science, such as macroergonomics.

That approach, the IPDP, is divided into phases. One of them is Informational Design. This phase is responsible for identifying the requirements, specificities and real needs of the users for whom the final product is intended for later converting them into product requirements. In this phase, Design for Assistive Technology [4] is approached, which involves Universal Design – which is a procedure of develop products and services that understood and can be used to the greatest extent possible by all users regardless of their age, size, ability or disability, not taking risks for them [27] –, Usability, Ergonomics and pleasantness for the three groups of users: a) primary: one who has direct contact with the product; b) secondary: a person with direct contact with the primary user and; c) tertiary: a professional who performs maintenance, assembly, confection and product indication services, such as physiotherapists, technicians and occupational therapists [4]. In this research, the three groups of users were considered, in order to enable multidisciplinary knowledge with a transdisciplinary process. In this way, considering the assistive technology users and the understanding their specifities, it is possible to create a device, which is directed to their needs and capabilities of them, aiming maximizes the functionality and increasing their social participation [28].

1.3. Transdisciplinarity and Macroergonomics: Socio-technical System

Ergonomics encompasses studies on the interactions between human beings and other elements or systems, so any research in this area must involve the human being and its interaction in a specific context of activity to carry it out.

"The ergonomists are responsible to planning, designing and evaluate tasks, work stations, products, places and systems in order to become them compatible with the specificities and the limitations of the users" [12,13,28]. Their activities can fluctuate in areas as health care, security, products design or work design.

In order to do those activities, the ergonomists have in-depth knowledge in many sciences, such as anthropometry, biomechanics, anatomic, human physiology, psychology, engineering and any area that can be necessary to know. Therefore, the ergonomics is about a transdisciplinary approach, considering it aims to resolve the problem of a world based on an academic experience or not, gettering the knowledge in order to propose solutions. That means, it transcends the approach of each discipline, and it urges throughout a single approach that can provide a new vision of nature and the reality [11,12]. It is about to establish a unique methodology. For that, each professional must not work in a targeted way as a multidisciplinary approach but must contribute proactively in front of an issue.

The object of the ergonomics, the work, is not only physiological or biomechanical. It synthesizes all those areas in order to make it more effective, comfortable and secure, which means that the solutions must be proposed considering all those areas. That is why ergonomics is a transdisciplinary approach [11,12,28].

Among the tools of ergonomics, there is the analysis of the sociotechnical system, which verifies the set of personal, technological, organizational subsystems and the internal and external environment directed towards macroergonomics [30].

Regarding the differences and specificities of the prosthetic device users, considering the poverty and vulnerability levels of Brazil and the background of the PwD, the technical solution to be adopted must consider the human factors and the transdisciplinarity in the problem. Thus, it was chosen the Sociotechnical system analysis. Analysis of the user's sociotechnical model takes into account an ergonomic approach, considering physical, psychological, social aspects of users crossing this information with the product's interaction data, in order to optimize human well-being and analyze the user specifics [10,11,13]. Adopting a sociotechnical approach to product development leads to a product that can be more acceptable to end-users and deliver better value to the final design [31].

2. Methodology

It is an applied nature research methodology, as it aims to generate knowledge for the understanding and practical application of a phenomenon. The research approach is quali-quantitative with an exploratory and observatory purpose, as it seeks to describe and investigate the phenomena of reality and to transform qualitative information into quantitative, as different areas of study were involved and that complement and express the research scenario. The technical procedures followed the stages of research methodology, as follows: a) To constitute the bibliographic review based on the concepts and tools of IPDP, Assistive Technology, Universal Design, Ergonomics, sociotechnical system involving the Social, Cultural, Physical, Psychological and Rehabilitation areas of users; b) Conduct exploratory research, with an observational basis, in the field, in order to understand the context of AT users. In this stage, seven events opened for public-oriented for PwD were attended by a transdisciplinary crew, including ergonomists, engineers, nurses and physiotherapists. In these events, over two thousand PwD was gettered; c) Elaborate and apply the questionnaire of social-technical analysis based on the observational research in the field and the bibliographic review. The application of this questionnaire was carried out by health professionals at a non-profit institution, who were physiotherapists, social workers, psychologists and occupational therapists. The institution is a support network for people with physical disabilities of agenesis and malformation of members and has a partnership term with the Research Center of Higher Education Institution. The questionnaire was applied to one hundred and thirty users who had direct or indirect contact with prosthetic devices for more than a year to participate in the research. The questions involved social, physical and psychological characteristics: gender, age, the region of residence, family income, education and the relationship with the devices. In addition, variants to be considered in the study of ergonomics such as use factor, safety, pleasantness and reliability of a device were measured and defined. In order to provide real statistics and make the research stronger, the Likert scale was used to analyze data on the personal importance of each requirement. This tool provides a better level of evidence and guarantees the findings; d) Analyze the data collected, from the crossing of information and constituting the Informational

Design structure and direction to the Conceptual Product Design in the structure of the Design for Assistive Technology.

3. Analysis of Results and Discussions

3.1 Assistive Technology Users in the field

Observational-based exploratory research took place at seven events open to the public and aimed at PwD. Simultaneously, the AT market and the use of prosthetic support devices for upper limbs in social internet networks were explored. In the public events attended, it was observed that each group of people with disabilities uses resources or adapts, according to their specificities, to everyday situations, using specific skills. This stage was important for understanding the visible specificities of PwD.

3.2 Analysis of the sociotechnical system

The analyzes of the social-technical system considered the following variants, illustrated in Figure 1, which exemplifies the answers:

(A) Do not harm the skin
(B) Provide security
(C) Easy to wear
(D) Easy to clean
(E) Be light
(F) Low cost
(G) Good appearance
(H) Size adjustment
(I) Do not cause pain or discomfort
(J) Do not require to use another product
(K) Low volume
(L) Be discreet
(M) Facilitate to handle things

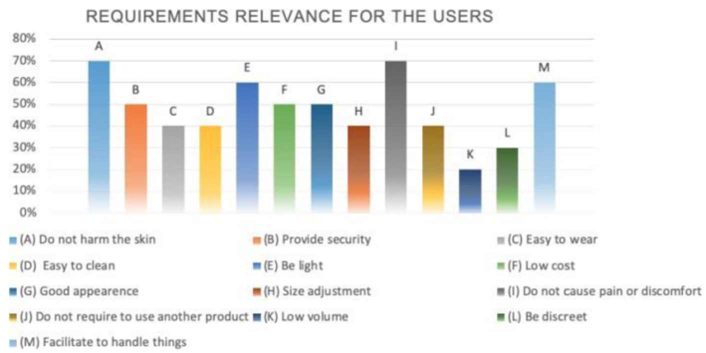

Figure 1. The scale of requirements for the user.

Besides, there was a field to specify points that were not suggested. In this data collection, it was noticed that most users who participated were women (81 users). In addition, most were over 30 years old (113 users), received between one and two minimum wages (98 users) and had a high school level (49 users). Regarding the variants, it was stipulated that would be considered only those that 50% or more of the individuals indicated a maximum degree of importance. Therefore, the requirements (C), (D), (H), (J), (K) and (L) were disregarded. In the optional field, users pointed out the items "can be customized" and "presents easy maintenance", totalizing nine influencing factors of which the device accomplished eight and failed in one: (B) provide security, as it did not have an anchorage fixed on the user's body.

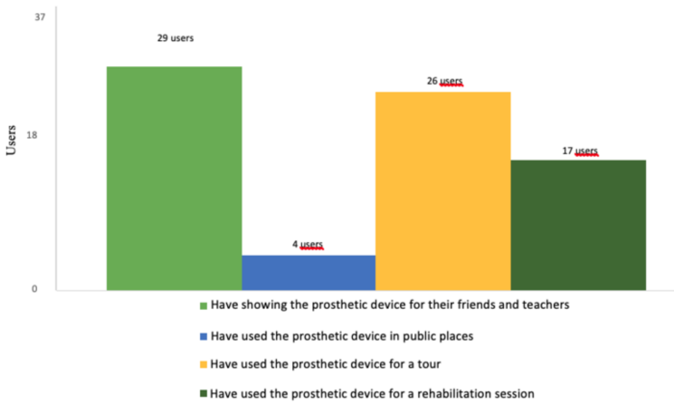

Figure 2. The behaviour of prosthetic device users.

Besides, it was made another data collection in a fraction of those users. This time, it was analyzed the behaviour of them – including adults and children – that used a prosthetic device for at least a year, in front of daily events in a group of thirty-seven people. The Figure 2 illustrates the graphic of the behaviour of prosthetic device users given by the rehabilitation team, psychological and educational follow up, which belong to the board of professional volunteers from de association. They present the following aspects: a) most of the children who received the prosthetic support device took it to the classroom (29 users); b) adults prefer to use it without exposing. Only 4 users used in a public environment; c) 26 users used the device at least once in the external environment; d) 17 users used in rehabilitation sessions. The behaviour of the users identifies that there is greater motivation to use the prosthetic device among children who are encouraged by the parents and colleagues in the school environment.

Table 1. Results from the analysis of the user's requirements.

Universal Design Principles	Does the device offer the principle?	Additions
Principle 1: Equitable use	It does not	It should offer an operation indication
Principle 2: Flexibility in use	It does	It works just flexing the elbow
Principle 3: Simple and intuitive use	It does	It works just flexing the elbow
Principle 4: Perceptible Information	It does	The expectations were wearing it and flexing the elbow
Principle 5: Tolerance for error	It does not	It does not offer a signal for incorrect use
Principle 6: Low Physical Effort	It does	It works just flexing the elbow
Principle 7: Size and Space for Approach and Use	It does not	It does not need much effort to work

Usability Principles	Does the device offer the principle?	Additions
The products must be predictable	It does	The product is made using user parametrization
The results of any action must match with the expectations	It does	The expectations were open and close the hand

It must be positive learning sharing	It does	The user receives rehabilitation sessions in the beginning
It must respect the human variability	It does	The product is made using user parametrization
It must prevent mistakes	It does	The device stops to work, needing a maintenance
It must feedback	It does not	It could offer a sound reply

Users Principles	Does the device offer the principle?	Additions
A. Does not harm the skin?	It does	The device is tied with confortable fabrics
B. Provides security	It does	The device works tied to the user
E. Be light	It does	It is made by plastic
F. Low cost	It does	It has a low price
G. Good apparance	It does	It offers simples and discreets lines
I . Does not generate pain	It does	The device is tied with confortable fabrics
M. Facilitate to handle things	It does	It helps to daily actions, such as to eat
N. Offer to be customizes (for the users)	It does	In the manufacturing, the 3D printer can create anu customization
O. Offer easy maintenance (for the users)	It does	In the Design is applied tools of Design for Assembly

Thus, from the analysis of the variants and the exploratory research on the use of the prosthetic device, a survey was carried out considering the principles of Universal Design, together with Usability and user's behaviour. Table 1 shows that 17 from the 22 requirements were met, corresponding to 77%. However, the requirements that did not match the principles were those that did not apply to the analysis of the prosthetic device of the upper limb, such as Principle 1 of "Equitable". Also, the Principle 7, "Size and Space use" of Universal Design, which is intended only for a person with limb agenesis and uses only on the side of the amputation was not considered. And, for the same reason, the Usability Principles to prevent errors of use or to issue a usage alert, had been disregarded. From the data collection, the phase of Informational Design was constituted. That one is responsible for the concept the forms, lines, functions, materials and experiences of the final product being reported on another fraction of the research. Nowadays, this prosthetic device is on the feedback phase, as Figure 3 shows.

Figure 3. The Prosthetic device for upper-limb agenesis.

4. Conclusion

In this research, the approaches of Universal Design, Usability and Ergonomics, as well as sociotechnical analysis, have practical applicability within the Product Development Process-oriented to Assistive Technology for the Informational Design phase. The research involving the sociotechnical system was carried out for primary, secondary and tertiary users of upper limb prosthetic devices, who were mostly located in urban and metropolitan regions with the level of education above high school. It should be noted that professionals qualified in the areas of health, pedagogy, rehabilitation an engineering participated as tertiary users, who have higher education and reflected in the results of the sociotechnical analysis, providing different multidisciplinary expectations and in the analysis of transdisciplinary processes. According to the collaborating institution, only those who have access to the internet network participated, noting that most of their registered associates contact only via mobile device with limited access. Therefore, the family income and education variations show a sample of users with access to information and greater interaction with the community of users of prosthetic devices.

These results were transferred to the IPDP Conceptual Design phase to define the structure of the prosthetic device, and then to the Detailed Design. In this way, there is the comprehension of the processes involved in the ability to analyze biomechanical movements, psychological aspects, safety and the possible bodily consequences resulting from the interaction of the human body with the environment.

In this study, the tools used to demonstrate that the product meets almost all requirements, except those that have indirect influences or were not part of the users' context. However, the deepening in the tools of macroergonomics applied in Design for Assistive Technology, identify requirements that interfere in the functionality of the product to adjust in the final prototype.

In the survey of the user's behaviour, it was found that it needs greater encouragement and awareness to participate in rehabilitation programs, which reflects in better performance and quality of life with the proper use of the prosthetic device.

In addition, this research seeks to develop lower-cost product designs, corresponding to the user's expectations. Thus, alternative materials are sought that correspond to the users' expected quality and contribute to the advance of technology to meet the areas of diversity and accessibility.

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Automatic Radiographic Bone Age Assessment Using Deep Joint Learning with Attention Modules

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Abstract. Hand and wrist skeletal radiographs serve as an important medium for diversified medical and forensic tasks involving bone age assessment. As an alternative to traditional atlas-based bone age identification techniques, deep learning algorithms automatically classify the radiographs into predefined bone age classes, provided that the deep neural networks (DNN) have been well trained with large scale annotated datasets. Most of the current bone age classification DNNs directly explore the existing network models developed for other computer vision representations and understanding applications, such as VGG, Inception, and ResNet. In this work, we present a multi-scale attention-enhanced classifier with a convolutional neural network backbone, specifically designed for bone age prediction and trained to learn a subject's bone age and gender jointly. The proposed classifier is trained with the dataset provided by the RSNA machine learning challenge, and the low-level semantic features are then transferred to a smaller Tongji dataset collected from a hospital in China. As demonstrated by the experiments, the proposed classifier achieves the MADs of 0.41 years over RSNA data and 0.36 years on Tongji data, outperforming other single model state-of-the-art and baseline algorithms for the same test. It illustrates that joint learning of gender information plays a critical role in refining the bone age assessment, while the convolution-based attention mechanism helps retrieve the key features.

Keywords. Attention mechanism, bone age, convolutional neural networks, joint learning

Introduction

X-rays and other medical imaging techniques have dramatically changed the landscapes of modern medical practice. One specialized application of the X-radiographs is to provide the evidence for radiologists to estimate the bone age of a child, based on the belief that the radiographs of hand skeletons reflect the maturity degree of the child's bones [1]. Although most children have bone ages identical to their chronological ones, an individual's bone growth may be affected by many other elements, such as genetics, hormone levels, dietary habits, and metabolic disorders, etc. In practice, accurately estimating bone age is critical in identifying many growth-related problems.

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Conventionally, radiologists search in an atlas for a match by visually examining the similarities with the X-ray image, as established in the Greulich and Pyle (GP) method. To reduce the human bias in comparison, the Tanner and Whitehouse (TW) method requires the evaluation between more specific regions of the radiographs and introduces a set of detailed features for the systematic scoring [2] (see Fig. 1 for an example). Atlas-based bone age assessment relies on the standard atlas and personal judgment. Therefore, sometimes two radiologists may disagree on the prediction for the same radiograph. In the past decade, machine learning has made innovative progress in understanding and interpreting medical data. Especially, assorted deep neural networks have proven their potential in assisting the doctors to diagnose many diseases [3, 4]. Several factors contribute to the successes of deep learning applications, including the increasing computing power, more sophisticated network architecture, and the large annotated datasets. Nevertheless, labeling the large dataset is a nontrivial project for most medical tasks. In addition to the reluctance from the medical institutions to share their privacy-sensitive data, the data labeling process is both laborious and costly. As an alternative, transfer learning enables a new application to take advantage of the knowledge learned from other domains, and thus eases the burden of developing large data sets from scratch.

In 2017, the Radiological Society of North America (RSNA) organized a pediatric bone age machine learning challenge. Deep neural network methods won an impressive advantage over competitors in this challenge, with the few best results about 4 months in mean absolute difference (MAD) on test set [5]. Since the bone age only marks the average development phase of bones for the children at a certain age, it exhibits large variabilities across different economies, regions, and races. Therefore, model refinement is needed when the target group differs from RSNA sources.

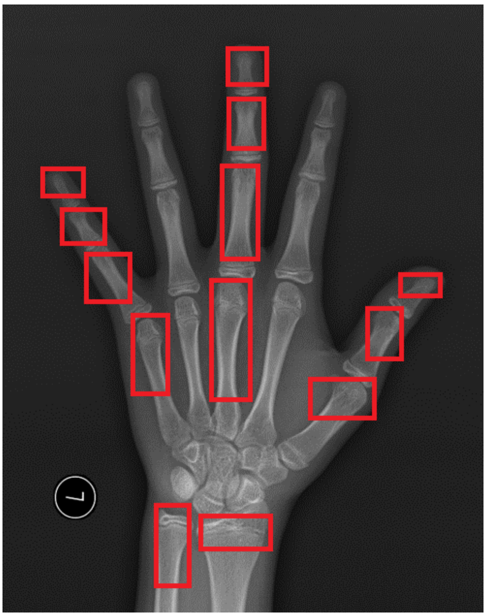

Figure 1. Some of the selected regions of interest (ROI) in specific bones of the wrist and hand used in TW method.

In this paper, we propose a multi-scale residual neural network (termed TJ-Net in this paper) for radiograph-based bone age prediction, introducing the attention mechanism to highlight the features important to the age group classification. Our earlier research reported that the features for bone age assessment could deliver a meaningful sex classification [6]. In this work, we extend this finding to a joint sex and bone age learning framework. The extensive experiments confirm that the learned features are in line with the traditional atlas-based assessment and transferrable to other datasets.

1. Related Work

The rich representation learning capabilities make the convolutional neural networks (CNN) and their variations one of the most successful deep learning tools in computer vision tasks [7, 8]. With CNN's ability to learn semantics-level features, [9] uses CNN to match the GP style atlas, and [10] uses CNN as a feature extractor for support vector machines to finish the classification of bone-ages. Most deep bone age assessments directly take the existing CNN models such as VGG16, Inception V3, and ResNet50 as the backbone, followed by a couple of dense layers to conduct regression or classification ([11], [12]}, and [13]). In [14], the authors take the pretained ImageNet and further fine-tune the classifier, generating an attention map similar to the ones used by human experts. [15] examines several bone age assessment DNNs consisting of convolutional and regressional layers. To focus on the specific regions in a radiograph that are believed to be critical, in the preprocessing stage, people either manually or automatically detect these regions in the hand skeleton ([16], [17], and [18]). Also, data augmentation can help alleviate the overfitting of some models, thus many proposals take random flips, crops, and contrast adjustment for image preprocessing [11]. [12] proposes an ensemble to integrate the estimates by three hand sections. The large dataset provided by RSNA laid the foundation for further improvement of applying DNNs in bone age assessment [5]. In addition to the pixels in radiographs, sex information input proved to help improve bone age assessment [5]. Furthermore, [19] explores the correlations between the models submitted to the RSNA challenge and achieves improved performance by combining the less-correlated ones into an ensemble.

2. Proposed Method

The proposed bone age classification network, called TJ-Net in this letter, consists of several functional blocks. Fig. 2 outlines the two-pronged architecture of TJ-Net. It maps an input image into one of the 77 bone age classes (corresponding to 0-19 years with a 3-months basic unit), as well as a binary gender label (the gender classifier, i.e. block 5, will be discarded in the test stage). The first 4 cascaded blocks in TJ-Net extract the crucial features from the input. Block 5 fuses the multi-scale features into the high-level ones for a dense layer to finish the sex classification. Block 6, the age classifier, matches the image features and the sex input into predefined age categories. The separate sex input supplies additional information for age classifier to adjust the result, and the sex classification helps to learn the bone features applying to both age estimation and sex labeling.

Each of the blocks 1-4 of the network comprises convolutional/pooling parts. The final output comes from a softmax function, and blocks 5 and 6 have fully connected layers. Fig. 2 also lists the network parameters along with the components.

We introduce the modules CBAM (Convolutional Block Attention Module), IncRes (Inception ResNet) into TJ-Net explores the attention mechanism, residual learning, and multi-scale features to empower the bone age-related feature extraction.

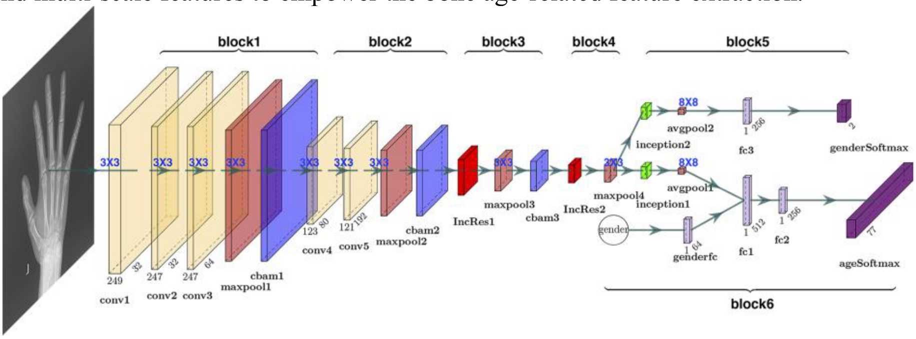

Figure 2. Architecture of TjNet.

2.1. Convolution-based Attention Modules

Among those channel and spatial features detected from the frontal convolutional blocks, the convolution-filtered features have varying importance in discriminating the bone age. The introduction of CBAMs is to enhance the features more relevant to the overall objective across the channel and spatial dimensions.

Following the practice in [20], each of three CBAMs in TJ-Net consists of two sequentially stacked components: channel attention and spatial attention modules. The input features first go through the average and maximum pooling layers in parallel, then two fully connected layers will produce a channel attention scale vector with sigmoid activation. The original input features weighted by the scale form a new tensor. This refined tensor subsequently walks through two parallel pooling layers the same as in the previous module (see Fig. 3). Then, the concatenated result gets processed by a $1 \times 7 \times 7$ convolution kernel. Finally, a sigmoid activation function outputs a spatial attention scale matrix. The output feature map is the multiplication of the scale matrix and the input features.

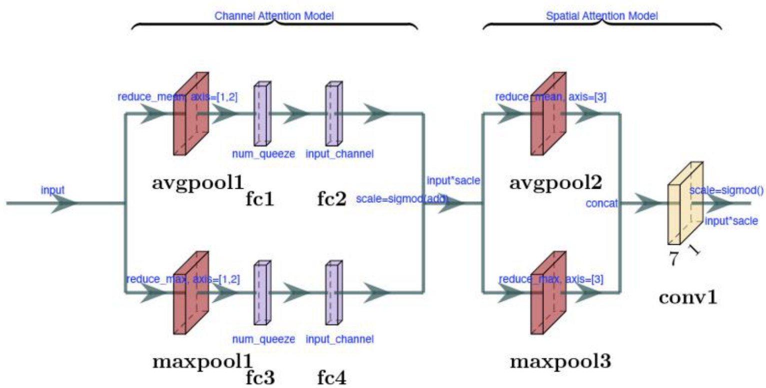

Figure 3. Internal structure of module CBAM1.

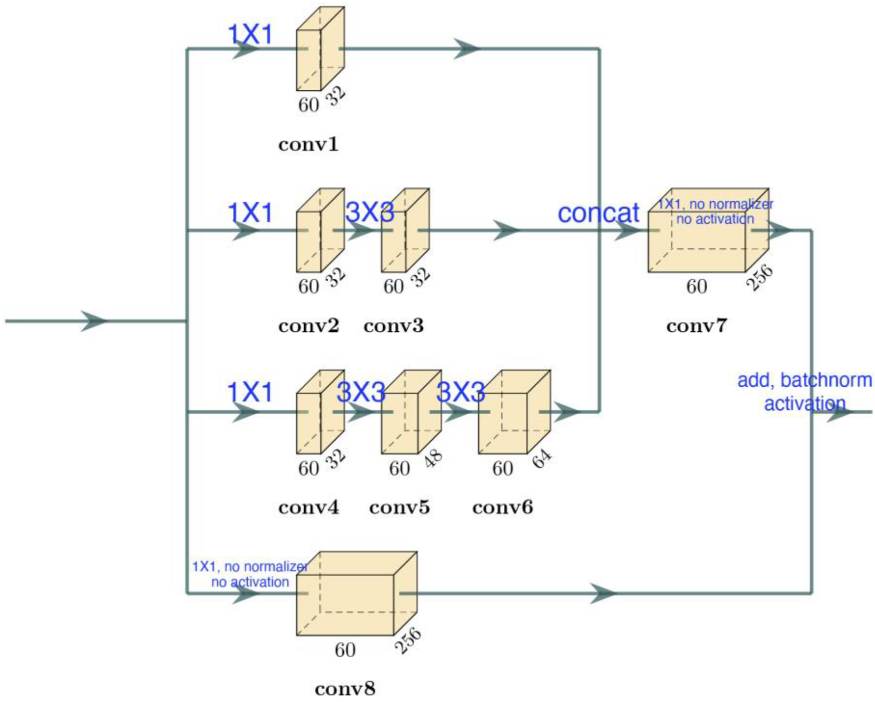

Figure 4. Internal structure of module IncRes1.

2.2. Inception Residual Modules

Local features in different scales may provide more and broader views to examine the relations between X-ray images and the bone ages.

There are two Inception Residual (IncRes) modules in TJ-Net, with slightly variant structures. Block IncRes1 consists of several branches with diverse convolutional kernel sizes (see Fig. 4). The multi-scale branches combine 1×1, and 3×3 convolution kernels in particular ways. Additionally, IncRes2 has four inception branches, namely 1×1, 3×3, 1×3, and 3×1 respectively. Similarly, each of the modules Inception1 and Inception2 has four multi-scale branches, the combinations of 1×1, 3×3, 1×3, 3×1, 5×5, 1×7, and 7×1. The convolutional outputs are concatenated in the later stage.

2.3. Loss Function for Joint Learning

The proposed loss function integrates the global classification errors over the training set, and the local sex/age batch-wise cross-entropies. Let n denote the size of dataset, g_i be the ground truth age label of sample i, and p_i be its predicted label. Let MAD be

$$e = \sum_{i=0}^{n} \frac{|g_i - p_i|}{n}.$$

We take an adaptive weight of $\alpha > 0$, to stress the importance of batch-wise errors in the early training phase. After the batch losses become stable, we shall let the global error to navigate the learning process by increasing α.

Denote the cross-entropy of two distributions p and q as

$$H(p,q)=\sum_{i=0}^{n}-p(x_i)\log q(x_i).$$

While at a certain age girls are roughly 2 years ahead of boys in bone development, it is not clear how the hand radiographs tell the difference between the two genders. However, gender labels can improve bone age assessment, as asserted in [5]. In other words, the conditional probability $P(age|gender, I)$ for a given X-ray image I helps accurately judge the age with the correct gender input. To better characterize this conditional probability, we shall learn the joint distribution $P(age, gender|I)$ from the training data by simultaneously minimizing the cross-entropies in a batch for both gender and bone age.

$$\mathcal{L}=\alpha e^2+\sum_i(1-\frac{|C_i|}{|C_t|})H(Y_g,P_g)+\sum_j(1-\frac{|C_j|}{|C_t|})H(Y_a,P_a)$$

where Y_g, Y_a and P_g, P_a are the ground truth gender/age frequencies and the predicted ones in a batch, $|C_i|$ and $|C_j|$ are the batch-wise cardinality of gender class i and age class$j$, i.e. the number of samples labeled as the class i or j accordingly, and C_t is the size of a batch. Introducing the ratio weight is to level the influence of different classes within a batch.

3. Experiments

3.1. Datasets and Preprocessing

We evaluated the proposed TJ-Net on both the RSNA data and the much smaller Tongji dataset.

There are 14236 hand radiographs in the RSNA dataset, where 12611 are used for training, 1425 for validation, and 200 for test purposes. However, since the competition has been closed, the test data is no longer available. Hence, we partition the original training data into training, validation and test sets by the proportion 0.8:0.1:0.1, leaving 1261 samples for test. Tongji X-ray images were collected and manually analyzed by a group of experienced radiologists with Tongji Hospital, a major teaching hospital affiliated to Huazhong University of Science and Technology. This dataset contains the radiographs of the (mostly left) hands of subjects ranging from 0 to 22 years old. We masked the original X-ray images to remove the private information. Because the original Tongji annotations were in years, we modified the network to output class labels in years.

In the raw X-ray images, hands might orient to arbitrary directions. We rotated these images to make the hands' orientation consistently upwards. After giving up the radiographs with poor quality, we kept 1385 images for the experiments. Tongji data distributes almost evenly in gender distribution, with 768 samples for female, and 617 for male.

Because RSNA data and Tongji data had different resolutions, they were both scaled down to the 500×500 pixels in size. We took this size to balance two factors: first, small images would leave out the necessary detailed for radiologists to make an informed decision; second, high-resolution images might slow down the learning process with the limited computing resources in our lab. Also, regular data augmentations were exploited in the online stage, including random crops, brightness changes, contrast variations, and flips.

Table 1. Comparison of Model Test Performances (in years) on RSNA Dataset.

Method	MAD	RMSE
VGG16	0.53	0.62
Inception V3[5]	0.57	0.58
Inception V4	0.59	0.97
ResNet50	0.60	0.72
TJ-Net	**0.41**	0.42

3.2. Implementation

We developed TJ-Net and other models in Python 3.6 with TensorFlow 1.7 framework. The hardware was a desktop computer equipped with one NVIDIA 2080Ti GPU card. All the models were trained using ADAM optimizer, with the batch size 16, and the initial learning rate 1^{-3}. When the training was close to being stabilized, we reduced the learning rate to 1/1000 of its initial value. It took about 15 hours for the training on the RSNA dataset, and 5 hours for fine-tuning with the Tongji data. To compare TJ-Net with other methods, we also developed the models using different backbones (e.g. VGG16, ResNet50, and Inception V4) with the separate sex input module and dense layers for classification [5]. These models were trained and tested on RSNA data. We followed the same protocol in all experiments: randomly choosing 80% of the data for training, leaving 10% for validation, and the rest 10% for test. To make the fair comparison, we tested Inception V3 with the RSNA data on the online server provided by 16bit, the top winner of the RSNA challenge (https://www.16bit.ai/bone-age).

In TJ-Net, the first two convolutional blocks feature small 3×3 kernels, to reduce the information loss of the images. In general, the features extracted from the first layers mainly capture the low-level vision details. Multi-scale deployment can extract multiple structural characteristics, and the residual link helps train the network. In the binary sex classification in block 5, we take only one fully connected layer of 256 neurons, to predict sex using the standard softmax function. The additional sex input block uses 64 neurons. Block 6, the age classification, has two dense layers, with 512 and 256 nodes respectively, followed by a normalized softmax function. Parameter α was set to 1.5 in the beginning, then boosted to 77 (the number of classes) after the loss became stable.

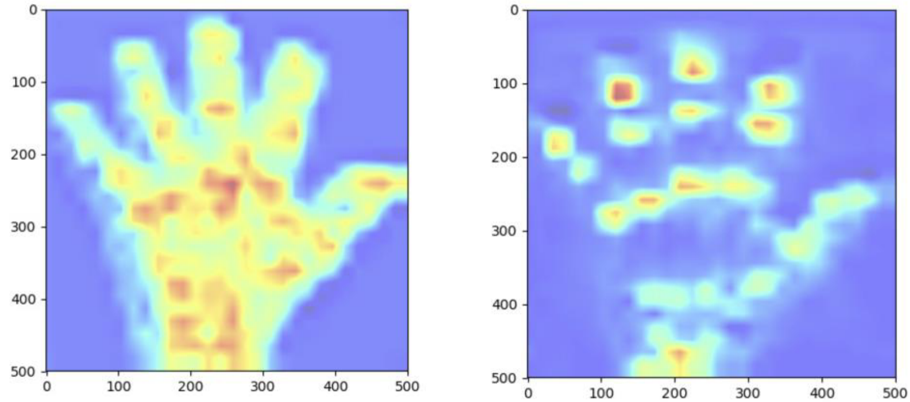

Figure 5. Comparison of the activation maps of block 4 learned without CBAMs (left) and with CBAMs (right), for a boy with the bone age labeled as 15 years old.

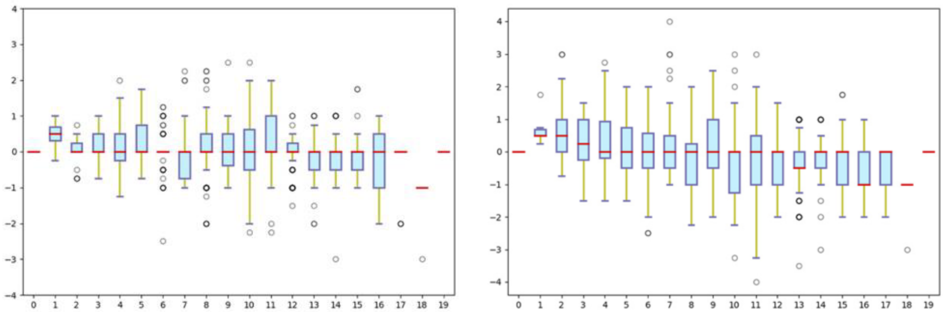

Figure 6. Comparison of prediction error distributions over age groups (in years) of RSNA data with (left) and without (right) joint sex learning.

3.3. Results and Analysis

Table 1 lists the comparison results of different models. We first trained TJ-Net with RSNA data and preserved the parameters of some blocks while fine-tuning the rest of the model with the Tongji training set. The MAD on the test set with blocks 1-3 frozen achieved the best outcome of 0.36 years (Table 2). It showed that our model TJ-Net was capable of capturing the critical features in assessing radiographic bone age and these low-level features applicable to different ethnic groups in distant regions.

Fig. 6 indicates that the predictions for both RSNA and Tongji data were basically unbiased. The errors for the two datasets were similar in distributions.

Table 2. Comparison of transfer learning results using different freezing strategies.

Pretrained Blocks	MAD	RMSE	Training Accuracy	Test Accuracy
Block 1	0.688	1.645	**0.996**	0.797
Blocks 1, 2	0.565	0.986	0.889	0.875

Pretrained Blocks	MAD	RMSE	Training Accuracy	Test Accuracy
Blocks 1-3	**0.362**	**0.551**	0.891	**0.922**
Blocks 1-4	0.638	1.072	0.879	0.883

To verify the effectiveness of different components in TJ-Net, we did the ablation analysis for the functional parts. We compared the resulting MAD and RMSE using RSNA dataset for the models, leaving one component out at each time. After eliminating the shortcuts in IncRes modules, the re-trained model obtained a MAD of 0.571 years. Similarly, without CBAMs, the simplified TJ-Net generated a MAD of 0.578 years, suggesting the positive role of attention modules. To visualize the impact of CBAMs on the trained model, we draw the heat maps of the activated features learned by block 4. In Fig. 5, the activation map with CBAMs pinpoints to the key locations similar to the ROIs examined by the TW method (Fig. 1), while the salient points found without attention mechanisms spread over a large area. Finally, if the gender classification and the associated loss were taken out, the MAD increased to 0.578 years. This indicates that joint learning improved the contribution of sex input in assessing bone age.

Figure 7. Comparison of the sex input weight matrices in block 6 without joint learning (top) and with joint learning (bottom), black represents 0.

The boxplots in Fig. 6 display the estimation error distributions for TJ-Net with and without block 5 and joint learning. Though the estimations are virtually unbiased, adding joint learning to TJ-Net allows more accurate predictions for most of the age classes. Moreover, in Fig.7 where the grey scales represent the strengths of the weights (black equals to 0), we see that joint learning makes the sex input weight matrix sparser, intensifying the influence pattern of sex input on bone age.

4. Conclusions

In this work, we proposed a specifically designed deep learning neural network, TJ-Net, for automatic radiographic bone age assessment. In TJ-Net, the attention modules helped find the features resembling the focal points explored by human experts, and the joint sex/age learning enhanced the predication of age conditional on sex labels. Experimental results demonstrated that the low-level features learned from the RSNA dataset could be transferred to the data acquired by a Chinese hospital from local subjects. With the MADs of 0.41 years and 0.36 years on RSNA and Tongji data, the proposed model performed better than other single model state-of-the-art methods.

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The Concept of Applying the Polyjet Matrix Incremental Technology to the Manufacture of Innovative Orthopaedic Corsets - Research and Analysis

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Abstract. Paper presents the concept of using digital materials to produce, by 3D printing, personalized orthopaedic corsets. Project assumes that corset created on the basis of a 3D scan and patient's x-ray, after posture correction in a dedicated program, will guarantee anatomical fit. Using additive manufacturing will allow to print shell and padding in one piece, without perceptible boundaries. Smooth combination of variable stiffness materials will allow precise positioning of the pressure surface with optimal shape. Soft padding protects against abrasions and microholes allow body to breathe. Using transparent and multicolour materials will allow creating an individual style corset. To implement the work, research was performed on materials used in PolyJet technology (new material is created in manufacturing process and has properties depending on proportion of base materials). Nonlinear tensile characteristics were obtained. Various models of hyperelastic materials were tested, parameters were identified and Drucker's stability criteria were examined. Using FEM, stiffness and strength of structure was tested. Values of stresses in structure and surface forces in body contact areas were determined. Corset closing pressure and corset opening were simulated.

Keywords. Orthopedic corset, posture defects, juvenile scoliosis, spine, 3D printing, PolyJet Matrix, digital materials, hyperelastic materials, model identification, FEM analysis

Introduction

Scoliosis is a lateral curvature of the spine - instead of a straight line, the spine is S or C-shaped. It can cause asymmetry of the waist and shoulder blades, rib hump, shoulder and hip irregularities. It is the lateral curvature of the spine, measuring at least 10° on the X-ray determined by the Cobb method [1]. Untreated cases of idiopathic scoliosis

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in adolescents (AIS) may progress and severe cases are at increased risk of various disease problems and mortality [2]. Particularly problematic are juvenile scoliosis, which start at the age of 4-10 years and deepen rapidly at puberty [3]. Scoliosis is the most common spinal deformity in school age children. Approximately 3 million new cases of this condition are diagnosed in the United States every year, the majority of which are idiopathic scoliosis in adolescents [4, 5]. Around 29,000 adolescent scoliosis surgeries are performed in the United States every year [5]. In many non-surgical AIS treatments, corset therapy (brace) is the only potentially effective method of preventing curve progression and the resulting need for surgery [6].

The consultation with Dr Waldemar Szymanik, Head of the Department of Children's Scoliosis in Mazovian Rehabilitation Centre "Stocer" in Konstancin-Jeziorna shows that in Poland annually about 3000 children require conservative scoliosis treatment and about 1000 surgical ones. Girls aged 10-15 years have scoliosis on average 7 times more often than boys.

The main element used in juvenile scoliosis treatment is an orthopedic corset. The corset is worn 22-23 hours a day and taken off only for exercise and bathing. After 3 months, pellets that increase the correction are glued inside. After 6 months the corset is replaced with a tighter one. The correction lasts from 6 months to several years, depending on the reason and degree of curvature.

The corset works by applying pressure on the arch of spine curvature and supporting it in two places on the opposite side, providing space for tissue outlet. This stops the progression of the curvature. Then, by introducing gradual pushing of the tissues surrounding the spine, the correct posture is forced (Figure 1).

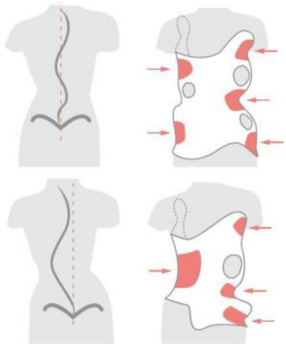

Figure 1. Corset operation - three-point pressure principle.

Making a corset requires a lot of knowledge and skills. It is necessary to create a model on the basis of which the corset will be made. The model is made using two methods: gypsum casting or milled model based on a 3D scan. The most popular and currently the cheapest method is the use of gypsum casting. However, this method requires exceptional qualifications, as it is performed manually (Figure 2). The method using 3D scanning technology is more expensive but less burdensome for the patient (Figure 3). The next step is thermoforming and - again - manual treatment (Figure 4).

The product obtained in this way is very frequently uncomfortable and not very aesthetic (Figure 5-a). Its aesthetics can be improved (Figure 5-b), but there is still the problem of fitting, fasteners and hygiene ,corsets are non-breathable products.

Cooperation of many people with an orthopaedic doctor is required for proper making of a corset. Any corrections and a new corset making are done by a technician on behalf of the doctor. Both the execution, as well as corrections and modifications require a high-class specialist in this field and a very large experience gained while working with many patients.

Figure 2. Making a corset model by gypsum casting.

Figure 3. Making a corset model by scanning and milling.

Figure 4. Thermoforming of a corset.

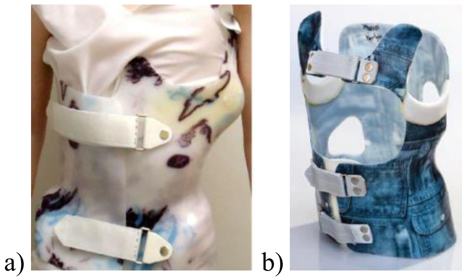

Figure 5. Examples of corsets.

Use of 3D printing in orthopedics

3D printing technology in combination with new imaging methods (3D scanning, CT) allows for effective elimination of many of the identified problems in the field of orthopaedic braces. Examples include innovative wrist orthoses [7]. It uses a hybrid production methodology that applies three-dimensional printing and injection moulding technology to create an orthosis, and the problem of gypsum casting is solved by a three-dimensional scanning method. Therefore, the proposed hybrid model significantly reduces production time and costs [8]. Similar solutions are successfully used in foot braces [9–11].

Currently, the listed methods of making orthopaedic orthoses are not cheap. However, taking into account the dynamic development of these technologies, printed orthoses will become cheaper. The Andiamo company estimates that in the nearest future their prices will be lower by 80% in comparison to traditional ones, and the time of production of the final product will be shortened to 2 days [12].

3D printing in the production of orthopaedic corsets

There are many examples of the use of 3D printing in, widely understood, orthopedics in literature. 3D printing is used both pre-operatively for surgical planning [13] and in the education of resident doctors and patients. It also found its place in the operating room, where it is used to produce customized surgical instruments or patient-specific implants. A number of authors highlight the significant benefits of using 3D printing for specific indications in spinal surgery. Although the use of this technology is often still in its infancy, it is stressed that it is a technology of the future. This is evidenced by many articles summarizing the use of this technology in medicine [14–17].

Most of the articles considering 3D printing in orthopedics focus on implants. The usage of 3D printing in orthosis production is a relatively new idea. This applies especially to orthopedic corsets e.g, „Lelio Leoncini, an Italian doctor specializing in Physical Medicine and Physical Therapy, began 3D-printing experimental "orthopedic corsets" in 2014." [18]

It can be stated that there are many companies that offer corsets prepared with the use of 3D printing technology [12, 14, 18, 19], but there is no corset mentioned in the literature that would implement all functions described in this project. Regardless of the method of manufacturing, there are usually two drawbacks: an additional inner layer is needed; when the curvature declines, another corset must be manufactured, due to the need to change the shape of corrective elements.

1. Aim and basic assumptions

The aim of this work is to propose a solution to eliminate most of the problems discussed. Generally, it has been assumed that using modern technologies and materials, it will be possible to develop a methodology for manufacturing corsets which becomes widely available for those in need, makes it easier to conduct treatment, increase accessibility and speed up the process of treatment, be relatively cheap to perform, easy to use, improve comfort and hygienic conditions, and look so that young people will not be ashamed to use them.

It was also assumed that the orthopaedic corset will be made on the basis of doctor's recommendations and a 3D scan of the patient's figure. Based on the results of the scan a 3D CAD model of the patient's torso is developed. Then a corset model is created. Based on the doctor's instructions, the position and shape of the correction elements are determined and then added to the model. The corset is made of various materials: external coatings are to provide adequate stiffness and strength, internal coatings – correction and comfort. In addition, the corset should enable making adjustments at every visit to the doctor and be unique in visual terms.

2. Methods and materials

2.1. Consultation with the medical community and patients

The work began with consultations with the environment of doctors, technicians and patients of the Mazovian Rehabilitation Centre "Stocer". Many opinions of the environment related to the use of orthopaedic corsets have been collected.

2.2. Design, CAD and FEM model

Using a system CAD/CAM implemented in Vigo Ortho-Poland, which is working basing on different data (anthropological measurement, x-ray picture, photographic documentation, measurements made during the Patient's visit), a 3D model were created. Next, using Rhinoceros 3D CAD system ver. Rhino 6.6 the design were created. Basing on the model from Rhino, using the Solid Works system the CAD model for the FEM were made. The FEM models were created using Abaqus CAE.

2.3. Technology

Taking into account the dynamic development of incremental methods and their increasing capabilities [20–22], it was assumed that the product would be made using 3D printing. This is closely linked to the choice of material, as the ideal should be characterised by a number of often conflicting features. The ideal material should: be biocompatible (allowed for prolonged contact with the body and not causing any allergies); waterproof (it cannot absorb sweat and dirt and has to allow the corset to be washed); provide adequate strength (it is supposed to carry loads ensuring stability, forces acting on the corset's fastenings, be characterized by resistance to cracking); provide a porous structure; enable a smooth, imperceptible and controlled transition from hard to soft surfaces; be UV resistant; allow the surface to be personalised with colour and relief; allow the effect of lightness to be achieved using transparent materials; the price of materials and production should allow the purchase of a new corset every 6-12 months.

Based on the authors' experience [23–26] detailed market research was carried out in the field of technology and material selection. It was not possible to find material meeting all of the above mentioned criteria. However, at this stage, due to the possibilities that allow for the realization of the basic assumptions of the project, digital materials[2] from the groups were used: Tango and Vero and PolyJet Matrix technology from Stratasys. In the chosen method, the product is created by mixing two materials with different characteristics (stiffness and strength), and the final properties are

[2] Digital materials - The term digital materials, according to the definition proposed in 2007 by George A. Popescu MIT [27], refers to materials made of different components that meet the following criteria: „The set of all the components used in a digital material is finite (i.e. discrete parts). The set of the all joints the components of a digital material can form is finite (i.e. discrete joints). The assembly process has complete control over the placement of each component (i.e. explicit placement).”.

obtained during the production of the finished element [28]. It allows to create structures that have changing properties in the cross-section of the structure. It is therefore perfectly suited for a project where relatively high stiffness and strength of the outer coatings and soft and susceptible inner coatings are required.

2.4. Materials

As mentioned, the project required a selection from a wide range of material properties [29] that would provide the right strength-stiffness parameters. Tango group materials are characterized by non-linear elasticity and the ability to achieve large elastic deformations (hyper-elastic materials), while Vero group materials have characteristics more similar to linear materials and achieve significantly lower elastic deformations. In order to verify the characteristics tensile tests were conducted [30].

2.5. Analyses

Finite Element Method (FEM) was used – implemented in Abaqus CAE 2019 system. The coefficients of constitutive models were identified on the basis of the obtained characteristics [30]. The next stage was the analysis of stability of the identified models using Drucker criteria [31, 32]. Based on the results obtained and using the Finite Element Method, numerical models were built, in which the rigid parts of the corset were defined as made of Vero25 material; while Tango85 and TangoBlack were chosen for the flexible parts.

A number of FEM analyses were carried out (including a set of utility loads, e.g.: corset opening, pumping correction elements, checking clamps and latches), which allowed to verify design assumptions, choose materials and introduce necessary modifications. [33]

3. Results

3.1. Problem map

On the basis of consultations with doctors, technicians and patients, a map of problems was defined, which is shown in Figure 6.

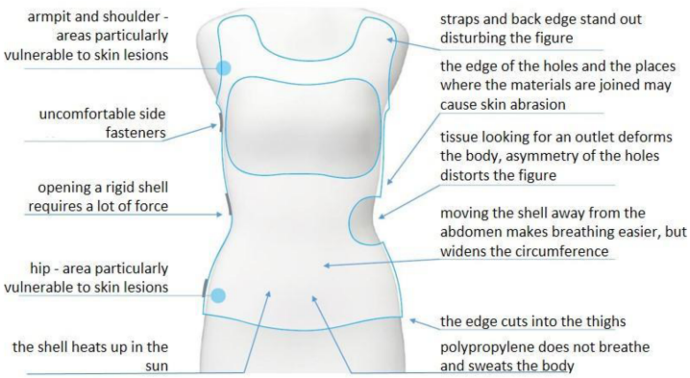

Figure 6. Orthopaedic corset - problem map.

3.2. *Identification of material models and numerical analyses*

The obtained results of numerical research are presented [34] and widely described in [33] and [35].

3.3. *Corset design*

These works led to the design of the corset (Figure 7), which is characterized by stiff outer shell and soft, fitted to the patient's silhouette, inner layer; adjustment of the shoulder straps pressure by pumping; possibilities to influence the stiffness of the structure by means of embossing and reliefs; soft profiling in the armpit area; soft hip protection; soft abdomen protection; buckles acting on the kandahar principle; adjustable by changing the pressure of the peloton - correction elements; two-stage, spring-loaded back and shoulder straps finish, preventing the edges of the corset from sticking out; perforations enabling the removal of heat and moisture from the body; soft spaces in any place and shape; elastic elements along the spine making it easier to put on and take off and improving comfort of use.

Figure 7. Designed corset.

4. Conclusions - Corset design for the 21st century

The market for medical products is quite hermetic. The main emphasis focuses on effectiveness. Therefore, products such as orthopaedic corsets are very often made as strictly medical products - without the involvement of specialists from various fields such as: industrial design, material engineering, modern methods: manufacturing, research and analysis. In this project, in order to obtain a design for the 21st century, it was decided to combine the forces of the above mentioned industries with the experience of orthopaedic doctors and technicians with many years of experience in making corsets. This was complemented by a series of consultations with the patient community, which is to be the main beneficiary of the achievements of this work. Using modern design methods, 3D scanning, incremental technologies, digital material capabilities and numerical computational methods, lead to creating a design that meets most of the postulates, which have been recorded in the work.

The design is a base with very high development potential. Apart from the aforementioned advantages, it has one of a vast importance: the possibility of more frequent and much faster corrections, performed directly by an orthopaedic surgeon - namely: a change in the strength of the corrective elements by changing the pressure in the "pellets" - which will translate into better results of the treatment.

On the downside, the material still has to be worked on. The material used in the project among others: can be allergenic, has a sharp smell, swells under the influence of moisture, is not biostable, and is relatively expensive. However, the test elements made allow for an optimistic perception of the project.

Especially if its developmental capabilities are taken into account, such as the ability to monitor wearing time (extremely important in the case of young people) - the possibility of installing sensors to record the history of use, especially the pressure in the cushions of correction elements, strains, forces in closures, etc. Or, the comfort of use test - assessment of the pressure on the patient's body - will allow for the optimization of the structure at the design stage.

The design was developed in cooperation:

- Doctors from the Mazovian Rehabilitation Centre STOCER, e.g. Dr Waldemar Szymanik, orthopaedic surgeon traumatologist, Head of the Scoliosis Unit
- Orthotics specialists from: Orthopaedic Laboratory Mark Protetik Non-public Health Care Facility
- VIGO Ortho-Poland
- BIBUS MENOS Sp. z o.o.
- Academy of Fine Arts, Faculty of Industrial Design
- Warsaw University of Technology, SiMR Faculty, IPBM, Manufacturing Technology Faculty
- Warsaw University of Technology, SiMR Faculty, IPBM, Material Strength Laboratory
- Warsaw University of Technology, Faculty of Materials Science

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Evaluation of Humanoid Robot Design Based on Global Eye-Tracking Metrics

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Abstract. The first impression of robot appearance normally affects the interaction with physical robots. Hence, it is critically important to evaluate the humanoid robot appearance design. This study towards evaluating humanoid robot design based on global eye-tracking metrics. Two methods are selected to extract global eye-tracking metrics, including bin-analysis-based entropy and approximate entropy. The data are collected from an eye-tracking experiment, where 20 participants evaluate 12 humanoid robot appearance designs with their eye movements recorded. The humanoid robots are evaluated from five aspects, namely smartness, friendliness, pleasure, arousal, and dominance. The results show that the entropy of fixation duration and velocity, approximate entropy of saccades amplitude are positively associated with the subjective feelings induced by robot appearance. These findings can aid in better understanding the first impression of human-robot interaction and enable the eye-tracking-based evaluation of humanoid robot design. By combining the theory of design and bio-signals analysis, the study contributes to the field of Transdisciplinary Engineering.

Keywords. Humanoid robot design, evaluation, eye-tracking, global metrics

Introduction

Comparing with industrial robots, the design of humanoid robots requires more attention to their appearance design. Industrial robots are created for the sole purpose of performing repetitive tasks. On the contrary, the humanoid robots are normally designed for service and consumers would have to be comfortable being around and interacting with them. Hence, the appearance of humanoid robots, which plays a critical role in influencing human-robot interactions [1, 2], should be studied.

The appearance of humanoid robots provides six meanings, communication of aesthetic, symbolic, functional and ergonomic information, attention-drawing and categorization [1, 3]. In general, questionnaires and scales are widely used for evaluating product appearance [4]. Nevertheless, evaluation data extracted from these methods suffer from the problems of false feelings of inner states and subjective bias [5]. Hence,

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increasing studies have been done to objectively evaluate product appearance from physiological aspects [4], including eye movements, heart rate, blood pressure, facial muscle activity, voice pitch analysis, and brain imaging [6, 7]. Among them, vision is the first channel and receives the most information about a product. Hence, the eye-tracking received most of attention in evaluating product appearance [8]. It is expected that the eye-tracking method is agreeable to evaluating humanoid robot appearance design.

The previous studies found that eye movement parameters, such as fixations and saccades indicated user experience. Nevertheless, these parameters are normally affected by visual attention mechanisms and visual cues. Hence, instead of using these statistical parameters, this study investigates the possibility of evaluating humanoid robot design based on global eye-tracking metrics. Global pattern measures refer to the parameters derived from an overall perspective, and these parameters can be measured without reference to the scene to be viewed [9].

1. Literature review

Several studies evaluated the product design by tracking eye movements and explored the indexes of eye movements which can reflect the user experience of the product [4, 10, 11]. Recent studies showed that it is possible to find correlations between gaze and different aspects of design evaluation. The six most commonly used metrics are overall fixation count, percentage of the total time spent on each area of interest, average fixation duration, fixation count on each area of interest, average dwell time on each area of interest, and overall fixation rate [10, 12]. The average fixation counts normally have a positive correlation with the appearance evaluation score. It was found that users took shorter time to the first fixation and spent longer fixation time to the one they preferred [4].

Besides fixation parameters, saccade parameters have been used for usability studies, too [13]. The saccade duration represents eye movements well and corresponds to all other saccade and fixation parameters. Hence, it has been used to evaluate image quality [13]. Moreover, pupil size is the one widely used to evaluate product design, as it indicates emotions and cognitive states. However, there are some contradictory results in the correlations between pupil size and product design. It was found that users had a smaller pupil size when browsing the product they liked. While other studies found that users had a larger pupil size when evaluating the product they liked. The results may be explained by the effects of visual attention mechanisms [4]. Some parameters are generated based on fixations and saccades, such as the length of scanpath. It was found that a product with high user experience normally induces efficient scan patterns [12]. In other words, users took short scanpath on the product with a high user experience.

These findings may provide a foundation and reference for developing eye-tracking based evaluation methods. However, limited studies investigated the possibility of using global eye-tracking metrics to evaluate product design. Hence, it is really challenging to generalize the results of a specific product to other products. In this study, several global eye-tracking parameters are proposed.

2. Methods

2.1. Data collection

The eye-tracking data and evaluation of humanoid robot design are collected in the study of [14]. Eye movements are recorded by Tobii-X3-120 with a sampling rate of 120 Hz. The raw eye-tracking data is preprocessed by the I-VT fixation filter [15]. The eye-tracking data is time-series data, which can be presented as $\mathrm{E} = \{g_x, g_y, p_r, p_l, F\}$, where g_x and g_y are the gaze position of x and y coordinates, p_r and p_l are the right and left pupil size, respectively, and F is the fixation index. The gaze points that have the same fixation index belong to a fixation.

2.2. Evaluation of humanoid robot design

As discussed in the introduction section, the evaluation of product appearance includes the subjective feeling of aesthetics and functionality. In this study, the subjective feeling of aesthetics is measured with an emotion scale, which includes pleasure, arousal, and dominance aspects [16]. It is expected that emotional characteristics to robot led to users' acceptance of humanoid robots [17]. Hence, several subdimensions of emotions are questioned. The functionality is measured with smartness and friendliness scales [18], which is modified from the PHIT-40 questionnaire. Questions are adapted to suit the picture interaction with a robot. The PHIT-40 is proposed to evaluate humanoid robots, and has been modified and widely used to evaluate user preference of robot [17, 19]. The nine-point Likert scales are adopted to measure these aspects.

2.3. Eye-tracking data

2.3.1. Fixation counts, fixation duration of AOIs

A velocity-based method named I-VT is applied to identify fixations from raw eye-tracking data [15]. For each photo of robot design, six areas of interest (AOIs) are defined, namely, head, chest, right leg, left leg, right arm, and left arm. The fixation counts and duration are calculated for each AOI. AOIs, are user-defined subregions of a displayed stimulus [20].

2.3.2. ApEn of gaze velocity and pupil diameter

The gaze velocity is obtained by the differentiating method. Specifically, the Euclidean distance of the consecutive gaze points is obtained and multiplied by the sampling rate. The gaze velocity is a time-series data, $v_1, \ldots, v_T$. T is the number of gaze points in each pack of eye-tracking data. Similar to the pupil diameter, the ApEn of pupil diameters is calculated based on the normalized data.

The ApEn is calculated based on a series of data and two predefined parameters m and r. m is the window length, referring to the number of points in each window. r is the threshold of distance. To ensure the statistical validity of the ApEn, m can be set as 1 or 2, and r should be set as the value of the standard deviation of the entire time-series data multiplied by 0.1 to 0.25 [21].

2.3.3. Entropy of fixation distribution [22]

The entropy of fixation distribution can reflect users' choices in visiting more or fewer of AOIs, on more or fewer occasions. The entropy of fixation distribution is investigated from two aspects: fixation duration and fixation count. Fixation duration refers to the dwell time on the specific AOI, represented as Fd_k, k is the kth AOI. Fixation count refers to the number of fixations of specific AOI, represented as Fc_k. K is the number of AOIs.

$$\mathrm{FD} = \sum_{k=1}^{K} Fd_k \tag{1}$$

$$Ep_{fd} = -\sum_{k=1}^{K} \left({}^{Fd_k}/_{FD}\right) * \log\left({}^{Fd_k}/_{FD}\right) \tag{2}$$

$$\mathrm{FC} = \sum_{k=1}^{K} Fc_k \tag{3}$$

$$Ep_{fc} = -\sum_{k=1}^{K} \left({}^{Fc_k}/_{FC}\right) * \log\left({}^{Fc_k}/_{FC}\right) \tag{4}$$

2.4. Data analysis

Gaze points out of the photo of robot design are excluded for analysis. All the statistical analysis is performed with MATLAB 2019a. Two analyses are performed. First, repeated measures ANOVA is used to assess the statistical significance of differences in the fixation counts and fixation durations among the six AOIs. Post hoc analysis is conducted using the Tukey's honestly significant difference (HSD) criterion if any significance is found. The significance level is set at 0.05.

Second, the correlation analysis is applied to study the relationships between global eye-tracking metrics and subjective feelings. Pearson's coefficients are obtained and presented afterward. Following the study of [23], the eye-tracking data (E_{ip}) of each subject is classified into two groups based on the evaluation level of robot design. Evaluation levels are ranked as follows: "high" for the robot design that rated "6-9"; and "low" for the robot design that rated "1-5." The pupil diameters are subjected to great individual differences. Hence, the series of pupil diameters are normalized based on the maximum and minimum data and analyzed following the cloud model. The expected value (Ex), entropy (En), and hyper entropy (Hn) across the two levels are analyzed.

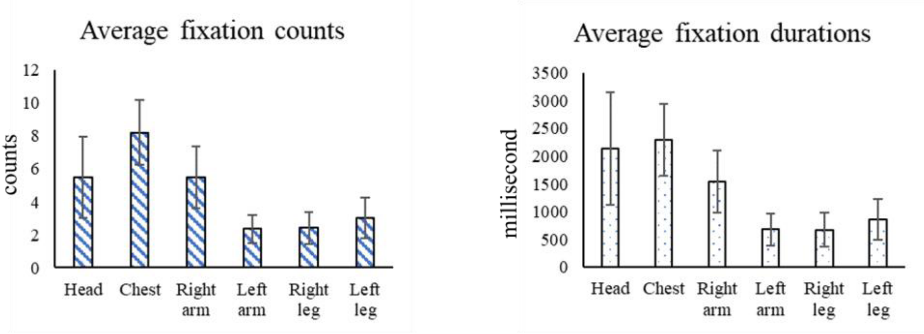
3. Results

3.1. Eye-tracking parameters and AOIs

Fixation counts of defined AOIs are shown in Figure 1(a). The ANOVA analysis reports significant differences in fixation counts between six AOIs ($F_{(5,102)}$=34.79, p<0.01). Specifically, most of the fixations located in 'Chest', followed by 'head' and 'right arm'. It can be found that 'left arm' is similar to 'right arm'. Nevertheless, significantly more fixations are put on 'right arm'.

Fixation durations of defined AOIs are shown in Figure 1(b). The ANOVA analysis report significant differences in fixation durations between six AOIs, $F_{(5,102)}$=28.49, p<0.01. Though significantly more fixations are found on 'chest' than on 'head', the total fixation duration of 'head' is almost the same with 'chest' (head=2137.50;

chest=2293.05). The results indicate that the mean fixation duration of ‘head’ is longer than ‘chest’, which may be caused by the complex design of ‘head’.



(a) (b)

Figure 1. Fixation distributions on six AOIs (a: fixation counts, b: fixation durations).

3.2. Correlations between global eye-tracking parameters and evaluation of humanoid robot design

Table 1 shows Pearson’s correlation coefficients between global eye-tracking parameters and subjective evaluation of humanoid robot design. The significant coefficients between global eye-tracking metrics and subjective evaluations can only be found in entropy of fixation count and fixation durations. Pupil dilations have high correlations with dominance while having low correlations with other aspects.

Table 1. Pearson’s correlation coefficients between global eye-tracking parameters and subjective evaluation of humanoid robot design.

Eye tracking metrics	Smartness	Friendliness	Pleasure	Arousal	Dominance
Fixation count_entropy	0.011	0.238**	0.124	0.084	0.031
Fixation duration_entropy	0.037	0.214**	0.164*	0.078	0.049
Pupil dilation_right	0.112	0.019	0.009	0.108	0.186*
Pupil dilation_left	0.142	0.072	-0.016	0.053	0.164*
Pupil_ApEn_right	0.027	-0.043	0.032	-0.023	0.168*
Pupil_ApEn_left	0.033	-0.019	0.048	0.083	0.112
Gaze velocity_ApEn	0.116	0.175	0.112	0.095	0.2**
Saccade amplitude_ApEn	-0.155*	-0.039	0.043	0.075	0.124

Note: *P<0.05, **p<0.01.

The ApEn of gaze velocity reports a significant correlation with dominance, while shows no significant correlation with other aspects. Hence, the ApEn would contribute little to the evaluation of robot appearance. For the ApEn of saccade amplitude, though no significant correlation is found between the ApEn of saccade amplitude and other aspects, the coefficient between smartness and the ApEn of saccade amplitude is significant. Since smartness is highly correlated with preference [14], the ApEn of saccade amplitude may contribute to user preference detection.

3.3. The cloud model of pupil dilations across apparent usability levels

The above analysis shows that the pupil dilations have low correlations with apparent usability. The results may be caused by the great variance and randomness of pupil diameters. In this section, the cloud model is adopted to visualize the distribution of pupil diameter across two levels of apparent usability and workload. Figure 2 shows the cloud model of pupil dilations. It indicates significantly different distributions of pupil dilations across two levels of apparent usability, except friendliness. Hence, it is expected that cloud parameters of pupil dilations can be used to detect apparent usability and assess preference.

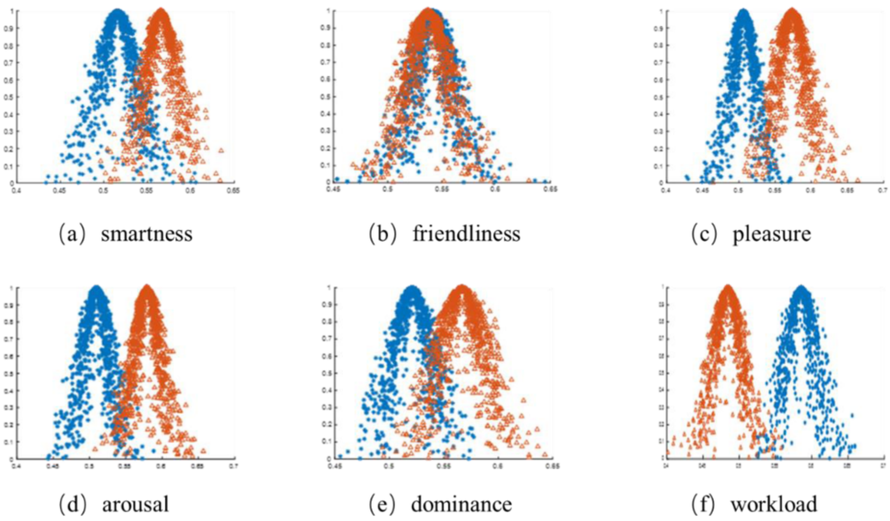


Figure 2. The cloud model of pupil dilations across apparent usability (blue: low usability; red: high usability).

4. Discussion

In the present study, we aim to determine whether global eye-tracking metrics could be practical indicators of humanoid robot appearance design. In particular, two types of global eye-tracking metrics were examined in terms of their correlations with subjective evaluations. The methods for generating these global eye-tracking metrics are all widely used for other biosignals, such as heart rate and brain dynamics [24]. Therefore, the global eye-tracking metrics are expected to reflect the changes in appearance preferences and can be measured without reference to the scene to be viewed, which makes it feasible to generalize the results to other product designs and apply the findings obtained from this study into practice.

Analysis 1 reports that most of the fixations locate in ‘chest’, followed by ‘head’ and ‘right arm’. Since the ‘chest’ AOI is in the center of the display, it is reasonable that subjects fixate on it [25]. The analysis shows that though ‘chest’ has most fixations, its mean fixation duration is shorter than ‘head’. The results may be caused by two reasons. On the one hand, ‘chest’ is the center part of robot design, users must scan across it to transfer among other AOIs. Hence, some short fixations may generate. On the other hand, the ‘head’ AOI delivers information of facial expression and human likeness, which are two important influencing factors of human-robot interaction [19]. Since the fixation duration depends on the amount of visual information [26], subjects generate long fixations in the ‘head’ AOI. A user’s perception of a robot can be strongly influenced by its facial appearance [27]. The results show that most of the fixations distributed on the faces of robots, supporting that facial appearance attracts users' attention. The previous studies pointed out that the spontaneous fixation positions were normally in the center or upper left [25]. It is reasonable to find that more and longer fixations were in 'right arm' than in 'left arm.'

The correlation analysis shows the possibility of evaluating humanoid robot design using global eye-tracking metrics. The entropy of fixation duration, the entropy of fixation counts, and ApEn of saccade amplitude are highly correlated with subjective evaluations. The positive correlations between the entropy of fixation counts and friendliness indicate that the randomness of fixation distribution increases with levels of friendliness shown by the humanoid robot design. In other words, subjects would fixate on some specific AOIs if they think the robot is friendly. If subjects dislike the robot design, their fixation distribution would be dispersed. The ApEn of saccade amplitude indicates the disorder and randomness of saccade amplitude [9]. The negative correlation is identified between the ApEn of saccade amplitude and the smartness level of robot design. The results indicate that subjects would randomly scan the robot if they feel that the robot is not smart. However, pupil dilations, ApEn of pupil dilations, and ApEn of gaze velocity do not report any correlations with subjective feelings except "dominance". This result is contradictory to some studies [4, 28], which indicate the possibility of using pupil size to detect preference, while it is consistent with some other studies, that stimuli category and gender difference may cause different variations in pupil size [8].

Considering the randomness and great variances in pupil diameters, the authors propose to classify pupil data into two groups according to the subjective rating of apparent usability and then generate a corresponding cloud model. It can be found that the cloud model shows the distinguishable distribution of pupil size across two levels of apparent usabilities, such as smartness, pleasure, arousal, and dominance. The results show the benefits of effectiveness, efficiency, and flexibility of the cloud model.

5. Conclusion

Users' preference of product design is normally established by the first impression. This study intends to investigate into the correlations between users' evaluation of humanoid robot design and global eye-tracking metrics. A case study is conducted with data from an experiment of evaluating humanoid robot design. The results show that the entropy of fixation count and fixation duration are closely correlated with the subjective evaluation. Hence, it is expected that they can be used to assess humanoid robot design in future works. The results show that pupil dilations have high correlations with dominance induced by the robot design while no significant correlation with other subjective feelings.

This study points out the benefits of global eye-tracking metrics in evaluating humanoid robot appearance design and provides some fundamental results. Nevertheless, only several aspects of humanoid robot design are studied. For future works, more influencing factors of appearance evaluation should be considered. An algorithm to evaluate humanoid robot design using the global eye-tracking metrics should be developed.

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Transdisciplinary Design Aspects of an Air Mobile Stroke Unit

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Abstract. Stroke is highly treatable but time critical. The greatest opportunity to improve outcomes is in the first 'Golden Hour' after onset. Pre-hospital care for stroke in Australia is patchy and poorly coordinated, resulting in gross disparities in clinical outcomes between rural and urban Australians. Clinical outcomes are at least twice as poor for rural Australians compared to their urban counterparts. A proposed solution is an Air MSU, an aircraft configured for rapid response to stroke victims so that diagnosis and treatment can commence onsite. This concept follows the tradition of the Royal Flying Doctors Service who have been providing medical services to rural Australians since 1928. This paper discusses the conflicting medical and aerospace requirements for an aircraft equipped with a CT-scanner including supporting equipment and personnel.

Keywords. Stroke medical response, Golden Hour, air mobile stroke unit requirements

Introduction

Worldwide, there are over 6 million deaths annually due to stroke. In Australia, the number of strokes is anticipated to increase from 60,000 to 132,500 per year by 2050. Stroke is highly treatable but time critical. The greatest opportunity to improve outcomes is in the first 'Golden Hour' after onset. Pre-hospital care for stroke in Australia is patchy and poorly coordinated, resulting in gross disparities in clinical outcomes between rural and urban Australians. The incidence of stroke is approximately 20% higher in rural areas, particularly for Indigenous Australians. Clinical outcomes are at least twice as poor for rural Australians compared to their urban counterparts. To optimise the pre-hospital treatment of stroke, a transformative research program is proposed to develop, test and implement novel disruptive technologies. The aim is to reduce morbidity and mortality, and narrow the urban, rural and Indigenous healthcare gaps. Part of this research program is the development of a Road and Air Mobile Stroke Unit (MSU) that can bring diagnostic and treatment equipment to the patient [1].

Stroke is a primary cause of death, disability, and dementia [2][3]. In the coming decades the prevalence of stroke is expected to increase because of the increase of the aged population in most countries [4]. Apart from considerable suffering for the patients and their families, stroke also results in enormous costs to society, costs associated with loss of work hours and with long-term care expenses [5][6].

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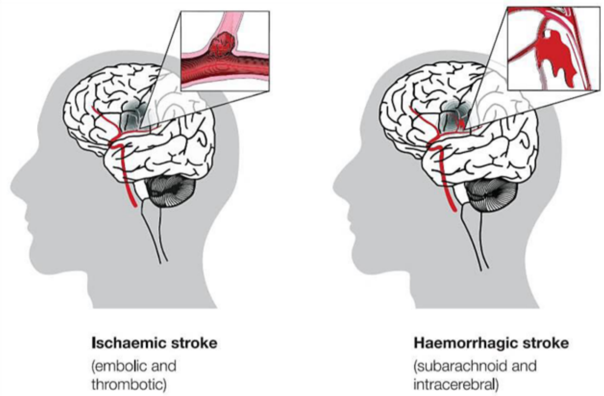

Figure 1. Ischaemic stroke and haemorrhagic stroke [2].

Two major forms of stroke can be distinguished (Figure 1). An ischaemic stroke is characterized by blocking (clots) of an artery transporting blood to parts of the brain. The second kind of stroke is the haemorrhagic stroke, caused by bursting of a blood vessel within the brain and floods the surrounding area. Due to the pressure in the artery, the rupturing blood can damage the sensitive brain tissue. Usually it is impossible to identify the stroke type on the basis of symptoms. Therefore, imaging tests of the brain are required to determine the stroke type and the extent of damage. Those scans can be performed by either a Computerised Tomography (CT) scan using X-rays for producing 2- or 3-dimensional images or by a similar Magnetic Resonance Imaging (MRI) scan which is based on generating a magnetic field and low-energy radio waves. In general, a CT is less sensitive than an MRI but is considered sufficient for the identification of an ischaemic stroke [7].

After the diagnosis of a stroke the patient should be treated as soon as possible to avoid further damageto the brain. Acute ischemic stroke is treatable by thrombolysis with recombinant tissue Plasminogen Activator (rtPA) or by removal of the clot in the brain-supplying vessel by Intra-Arterial Treatment (IAT) in case of Large Vessel Occlusion (LVO). Both types of recanalizing treatments must be delivered as quickly as possible after the onset of stroke symptoms because the chances of rescuing the ischemic brain from irreversible damage decline rapidly and even minutes of delay count [8][9]. Haemorrhagic stroke is treated by emergency surgery in order to remove the accumulated blood coming out of the ruptured vessel. Simultaneously the blood pressure needs to be reduced by using medication [9][10].

Air Mobile Stroke Unit (Air MSU)

Timely delivery of recanalizing stroke treatment is a serious medical problem, especially in countries with large remote areas and low population densities, in which coverage with specialized stroke centres is poor. Within a single country, the rural or urban setting and the associated distances to nearest stroke centre are key factors in the delivery of time-sensitive stroke treatment [11][12]. Reported times from symptom onset to admission to rural hospitals range from 5 hours to 30 hours [13][14]. In Australia, for example, the likelihood that patients in rural areas could access a stroke unit in time was only 3%, whereas the likelihood for patients in metropolitan areas was 77% [15]. These delays before hospital admission are a major reason for low thrombolysis rates of 1% to 6% for stroke patients in rural areas in different countries [16-19]. Such a disparity in regard to acute stroke treatment is a major medical problem not only in low-income countries but also in middle- and high-income countries, such as Brazil, Russia, the United States, Canada, and Australia [13,16-19].

A recently developed concept is the provision of diagnosis and treatment of stroke at the emergency site. This is based on a Road Mobile Stroke Unit equipped with not only the conventional ambulance equipment, but with all of the tools necessary for pre-hospital diagnosis and treatment, and a rational triage decision with regard to most appropriate target hospital: A computed tomography (CT) scanner for multimodal imaging studies, a point-of-care (POC) laboratory for all blood tests required for treatment in accordance with approval criteria [20] and stroke management guidelines [21][22] and a telemedicine connection to hospital stroke experts.

Trials have shown that this approach significantly reduces delays before intravenous (IV) thrombolysis [23-26]. The rate of patients treated within 60 min after the onset of stroke symptoms ("Golden Hour") increased dramatically, from 4% to 57% [23]. This reduction in delay before treatment is due not only to a reduction in transport times but also to the marked improvement in efficiency of interfaces between the many groups of health care professionals involved in stroke management [27].

The Road MSU is suitable for metropolitan areas, but cannot provide the response time needed to reach people living in rural and remote areas. An alternative is the design of an Air MSU that is equipped specifically to respond to stroke victims living away from a suitable medical centre. Mobile CT-scanners currently available are intended for use in hospital settings and medical centres, not to fly on aircraft. CT-scanner operating requirements are generally not compatible with the environment of flying in an aircraft. In addition, special requirements must be met to provide sufficient clearance for patient and medical personnel to perform the scan and treat the patient. The scan will take place on the ground, potentially in hot, humid, wet or dusty conditions, while some treatment may be necessary in flight enroute to the hospital.

This paper discusses some of the design challenges associated with incorporating a standard CT-scanner with support equipment and personnel on an aircraft, with consideration for cabin ergonomic design and aircraft safety and operating requirements.

1. Aeromedical Operations

Aeromedical operations involve an aerial transport vehicle, either being a fixed wing aircraft or rotary wing aircraft (helicopter) for the purpose of medical operations. These operations allow for medical practitioners to treat patients in a timely manner and in more rural and hostile locations compared to conventional road ambulance means. The aircraft used for these operations are purpose equipped aircraft, fitted with all required items to successfully treat a patient and provide transfer to the nearest available medical centre or hospital.

The crew operating these aircraft are trained flight paramedics and provide comprehensive prehospital,emergency and critical care to all types of patients during aeromedical evacuation or rescue operations aboard. The type of operations being undertaken within the aeromedical field range from inter-hospital patient transfers, permitting the transport of patients between hospitals, to neonatal operations for the transport of young infants, to full scale search and rescue and trauma patient recovery from vehicular accidents. No one aircraft type is specifically suitable for all aeromedical operations, resulting in different size and type of aircraft being used.

The coordination and execution of aeromedical operations is generally conducted from a single resource centre. These centres rely on communication resources such as data and satellite to relay vital information between aircraft and ground crews. In some instances, multiple aircraft can be required for a single mission.

1.1 Current Aeromedical Aircraft

Within Australia there are several different aircraft operators serving the numerous states and territories. These operators maintain the various aircraft used to support the Aeromedical industry. There are several different aircraft types currently in use for aeromedical operations. These aircraft are sized and equipped based on the different locations and purposes. These aircraft fall into two categories: Fixed-Wing (aeroplane) and Rotary Wing (helicopter) aircraft. Table 1 and 2 list the primary fixed wing and rotary wing aircraft which are currently being utilised within Australian for aeromedical operations.

Figure 2. Some aircraft types in the Victorian Air Ambulance Service and Royal Flying Doctor Service fleet.

Table 1. Aeromedical Fixed Wing Aircraft.

Manufacturer/Model	Category	MTOW kg	Payload kg	Range km
Bombardier Challenger 604	Jet Medium	21,909	2,189	7,628
Bombardier Learjet 45	Jet Medium	9,318	959	3,645
Pilatus PC-24	Jet Small	8,318	1,136	3,611
Beechcraft King Air 200	Turboprop Medium Multi	5,682	841	2,759
Beechcraft King Air 350	Turboprop Medium Multi	6,818	1,189	2,871
Pilatus PC-12	Turboprop Single	4,750	1,125	3,074

Table 2. Aeromedical Rotary Wing Aircraft.

Manufacturer/Model	Category	MTOW kg	Payload kg	Range km
Airbus BO 105	Light Multi	2,605	896	437
Airbus BK 117B2	Med Multi	3,357	1126	441
Airbus H175	Heavy Multi	7,515	2,582	722
Airbus H145	Med Multi	3,708	1,559	620
Bell 412EP	Med Multi	5,409	1,831	582
Leonardo AW139	Heavy Multi	6,414	2,173	1,074
Leonardo AW189	Heavy Multi	8,317	3,359	870
Sikorsky S-92A	Heavy Multi	12,045	3,371	810

1.2 Equipment Details

For effective patient treatment upon arrival, the Air MSU must accommodate all necessary medical equipment and personnel for diagnosis and follow-up treatment. The most critical item is the CT-scanner that takes “slices” of X-ray images, thus creating a 3D image of the brain. The image quality must be such that it shows vascular occlusion or blood perfusion to determine the cause of the stroke and its location. Mobile CT-scanners are designed to operate in a hospital environment and are not intended to be installed on aircraft. This is by far the most significant engineering challenge as CT-scanners are heavy, typically between 600kg to 800kg, and sensitive to vibration, external loads and environmental conditions.

The supporting medical equipment generally installed includes items to assist with patient monitoring and ventilation. These items are stowed in suitable mission cabinets and consoles throughout the cabin for efficient treatment. Table 3 lists the payload requirements for a typical Air MSU aircraft. The weight of installed equipment + crew + personnel is approximately 2,000 kg.

Table 3. Medical Equipment List.

Component
CT scanner system
CT scanner system batteries
Stabilization system
Telemedicine equipment
Computer Systems
Stretcher System
Stretcher System Restraint
Contrast medium injector
Heater/fridge
Technical Equipment Rack
Mission Console
Medical equipment (various)
Laboratory unit
Crew Seating (Standard)
Crew Seating (Swivel)

All the medical equipment listed is required to be stowed in accordance with load requirements as outlined by the aircraft certification. Accordingly, the utilisation of medical cabinets and consoles are necessary to stow loose items of mass. For larger specialised items, such as the CT scanner system, a bespoke load restraint system will be required. These types of systems will allow for the integration to the aircraft floor and cargo provisions and can incorporate provisions such as vibration suppression and stabilisation for the scanner, or patient turn tables and lifts for the stretcher systems.

1.3 CT Scanner System

For on-site treatment, a CT-scanner is required to help determine the size, location and type of stroke. A mobile CT-scanner is powered by either integrated rechargeable batteries or by an external power source. It can perform five to six scans or can be on standby mode for at least 8 hours. In-flight charging of the batteries can also be considered to extend the system standby time when not located at the base of operations. A tablet used for controlling and configuring the CT scanner is installed, however the system can also be operated remotely for operator safety and convenience. This is important in the Air MSU as cabin space can be restrictive.

The system has an operational temperature range of 10 °C to 40 °C. This range allows for operations in some of the more remote areas across the country. To assist, the aircraft on-board environmental control system (air conditioner), will ensure the system remains within the required operational temperature range.

1.4 Telemedicine Systems

To aid in the treatment and help in the preparation of hospital admission, tele-medical systems are installed to provide near real-time communications and data transfer between the in-field paramedics and the hospital-based neurologist at a Comprehensive Stroke Care Centre. These systems enable real-time digital transmission of the imaging and physiological data to ensure both the correct treatment can be administered on-site, but also provide the receiving hospital with the correct information to continue patient treatment upon arrival. The telemedicine systems currently operate on the 4G cell band for data transmission. In the event of a mission occurring outside of usable cell range, the system can convert to satellite communications to relay all required data.

1.5 Stretcher Systems

To work in conjunction with the MSU CT-scanner system, a suitable stretcher is required. The stretcher supports the patient during the scanning operations and, in the event of inter-hospital transfer, secure the patient in the aircraft or ground vehicle. Currently, in Road MSUs a specialised Stryker PowerPro XT stretcher is used, shown in Figure 3. This system provides a combination of flexibility and ruggedness for operations in all expected mission environments. The stretcher has adjustable height to suit the CT scanner. This is achieved with the integral hydraulic systems to permit the adjustment with zero-lift for operator safety.

Figure 3. Stryker PowerPro XT

1.6 Medical Crew Seating

During flight, the crew must be in a seated position. There are several crew seating options for integration into the aircraft. For treatment of the patient during flight, a purpose multi-mission seat is required. These seat types allow for translation and rotation. This provides the greatest flexibility to allow the crew to perform their required tasks. For Air MSU operations, specialist personnel are required to conduct specialist tasks and treatment. Seating provisions must be provided for the following medical crew:

(a) Paramedic
(b) Radiographer
(c) Nurse
(d) General practitioner or neurologist
(e) Second paramedic (highly desirable)
(f) Patient family (highly desirable)

2. Project Specific Requirements

2.1 Crew Requirements

Aeromedical operations are considered a specialised task within the industry. The crew who will be operating the medical systems will need to be fully trained and aware of these requirements when operating both in and around the aircraft. Further, crew will need to be trained on cabin layout and equipment operations to ensure they can perform their functions in a safe and efficient manner.

2.2 Landing Site

Potential landing sites within the region that are suitable for an Air MSU will need to be considered. The landing sites will need to account for the overall length, and maximum landing weight of the aircraft. An Air MSU based at a metropolitan hub will allow for the utilisation of the existing resources at both aeromedical operators and Stroke Care Centres who currently operate a Road MSU. This configuration of facilities will require some additional logistical capabilities to transfer the patient from the airfield to the hospital. Further to this, the airfield can support 24hr operations. This will allow for the use of ground power facilities to provide power to the CT scanners when not in use.

2.3 Vibration

The cabin vibration will form the major design point for the integration of the proposed CT scanner into the aircraft. Given aircraft, specifically rotary wing aircraft, are prone to heavy vibrations compared to road base vehicles, some form of isolation system will be required to protect the sensitive equipment. The levels of vibration in terms of both frequency and amplitude will vary for the selected Air MSU aircraft. Further, as vibration is a function of mass, a simple analysis of an empty aircraft will be insufficient to analyse the installation. Several test flights would be required:

(a) Bare cabin to determine a baseline vibration spectrum for the aircraft. The data captured can be used in conjunction with equipment providers to assess the suitability of the environmental conditions and determine any isolation requirements.

(b) Operations with a representative mass that mimics the CT scanner and equipment. This will allow the isolation system to be fine-tuned prior to operating with the scanner installed, thus preventing damage to the equipment. This will also provide a better understanding of the cabin configuration and weight and balance limitations with all items installed.

(c) Operations with the full system installation. This will provide a final in-flight test of the system to ensure the vibration isolation is adequate to protect the system.

Further to test (c), the vibration system can remain installed to provide continued vibration monitoring to ensure the system does not exceed any limits. This vibration system may also form part of the final restraint of the system for the CT Scanner.

2.4 System Installation

The aircraft must be certified to the latest crash requirements of FAR 25.561 (fixed wing), and FAR 29.561 (rotary wing) for restraining items of mass within a cabin. The intention of these requirements it to protect the aircraft occupants from injury in the event of an emergency landing. A breakdown of the load requirements is outlined in Table 4. As such, the CT scanner will need to be restrained to loads of up to 20g in some directions. The integration of the system into the aircraft will require some form of interface to secure the CT scanner to the aircraft floor and roof structure. Extensive analysis of both the scanner (including interface) and the aircraft will be required. While these design loads are high, it should be noted that corresponding requirements for installation within a road ambulance (AS/NZ4535:1998) are greater in some orientations.

Therefore, should a certification program be undertaken for the CT scanner, the data generated will be suitable across both platforms allowing for integration into a road fleet as well.

Table 4. Critical Design Load Factors.

Direction	FAR 25.561 Amdt 91	FAR 29.561 Amdt 38	AS/NZ4535:1998
Forward	9.0g	16.0g	20.0g
Downward	6.0g	20.0g	-
Sideward	4.0g	8.0g	10.0g
Upward	3.0g	4.0g	-
Rearward	1.5g	1.5g	-

The restraint of the patient and stretcher system will also need to be carefully considered. The patient it required to be restrained in the same manner as the seated occupants. Like with the scanner, a specialised interface may be required to permit translation of the occupant and stretcher to interface into the scanner.

2.5 System Loading

The operation of the system in terms of loading both equipment and patient will also be a critical factor. Given the size and weight of the scanner, special consideration will be required with developing the interface system. The need for translation along the cabin and forklift provisions will all need to be considered to allow for maintenance and reconfiguration of the aircraft. In conjunction with the loading of the scanner, patient loading, and positioning will also need to be considered. The patient will be required to be loaded firstly onto a stretcher and then into the aircraft. A typical Air MSU layout for the S-92A is shown in Figure 4.

With the safety culture in the medical industry, there has been a shift towards zero-lift operations. This safety element is a critical a part of the integration of the stretcher and scanner into the aircraft as these items must be loaded and secured with minimal operator lifting. The use of equipment such as stretcher loaders (*Stryker* Powerload) will be required for the patient loading phase of the mission, while items such as forklifts or cranes will be required for maintenance purposes to load/unload the scanner.

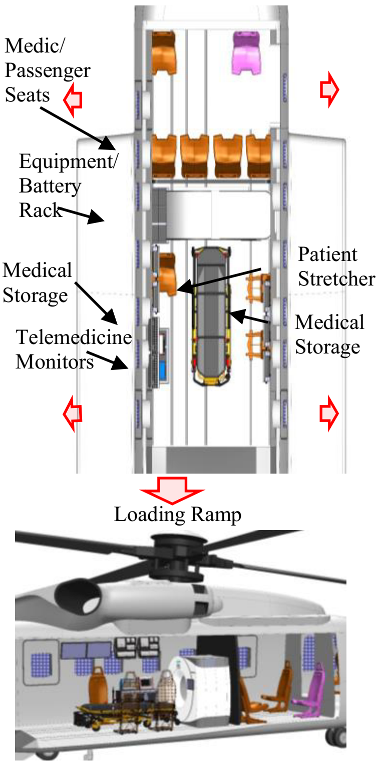

Figure 4. Typical Air MSU layout.

2.6 Payload-Range Performance

The main objective of the Air MSU is to provide diagnosis and begin treatment on a stroke victim within the first "golden hour". The Sikorsky S-92A can lift at least 3,000 kg of payload with sufficient fuel for 60 minutes of flight. This analysis includes a 30-minutes fuel reserve, but excludes time and fuel used during taxi, take-off and landing.

This can be increased by 544 kg with a Gross Weight Increase. With a payload of 2,000 kg, the performance is improved to 60 minutes operations without re-fuelling. The payload-range performance is shown in Figure 5.

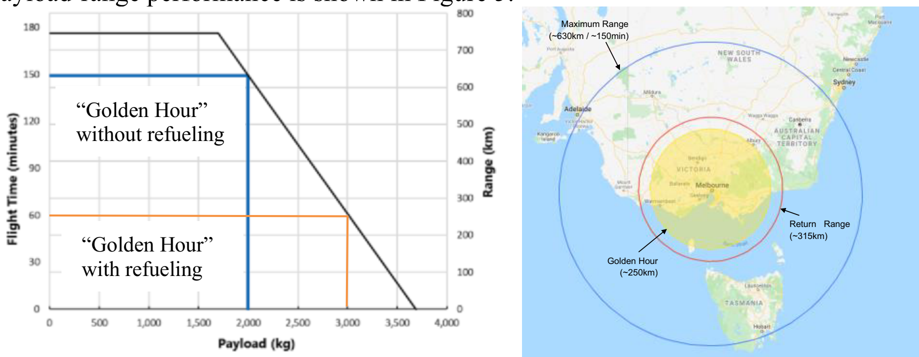

Figure 5. S-92A Air MSU payload versus range performance.

The proposed base for Air MSU operations is Essendon Airport in Melbourne, which is used as an aeromedical base for Air Ambulance Victoria, for fixed-wing aircraft and helicopters. With the cruise speed for the Sikorsky S-92A of between 252 km/h and 280 km/h, the capable range of 250 km can be achieved in one hour, the Golden Hour.

3. Conclusion

An Air MSU is proposed that can reach stroke victims in rural and remote areas as quickly as possible to allow for diagnosis and treatment to commence onsite. The design of such a solution requires close interaction between medical personnel, aerospace engineers and medical equipment manufacturers to ensure a vehicle can be designed for efficient and effective operations. The major engineering challenge is the CT-scanner which are not designed to be installed on an aircraft. They are relatively heavy and sensitive to loads, vibrations and environmental changes. This means that, in collaboration with manufacturers, a parallel effort is made to reduce scanner weight without affecting its functionality. Alternatively, new technologies are in development that would make CT-scanners more portable. The third stakeholder are the medical personnel that need to work in a confined environment and require ready access to the patient, equipment, and medical supplies. This paper presented an overview of requirements that must be considered from a medical and aerospace engineering perspective to ensure safe and reliable operation.

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Berth Allocation and Quay Crane Assignment Under Uncertainties

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Abstract. The integration of berth allocation problem (BAP) and quay crane assignment problem (QCAP) is an cardinal seaside operations planning, which is susceptible to uncertainties, e.g. uncertain vessels arrival and maritime market. This paper addresses the integrated optimization of BAP and QCAP under uncertainties. A stochastic programming model is formulated for minimizing the waiting time and delay departure time of vessels. Besides, numerical experiments and scenario analysis are conducted to validate the effectiveness of the proposed model.

Keywords. container terminal, stochastic programming, B&QCAP, genetic algorithm, uncertainty

1 Introduction

Maritime transportation plays an important role in driving economy growth and energizing the process of globalization, since its trade volume accounts for four fifths of the world's total merchandise trade. As the core node of maritime transportation, the efficiency of container terminal will directly affect the operation of maritime transportation. A total amount of the throughput of global container ports has achieved 802 million TEU in 2019, and it's expected to reach 973 million in 2023, according to the prediction of Drewry Shipping Consultants [1]. This means the throughput of global container ports is on the verge of a new billion era. Moreover, with increase of container vessel size, container ports are encountering another challenger, i.e. the repaid handling for mega container vessels [2].

BAP and QCAP are fundamental problems in optimizing container terminal operations, because berths and quay cranes (QCs) are the most critical resources in the front of the seaside. In particular, the integration of berth allocation and quay crane assignment secure an import position in efficient operation of container ports. Essentially, this integrated problem belongs to the intersection between the management and operations research. Up to present, plenty of studies were attempted in the integrated optimization of berth allocation and quay crane assignment in the static and deterministic environment. For a comprehensive overview, we refer to review the work given by [3,4]. However, most of the assumptions will hardly satisfied, e.g. the vessel arrival time and handling time. On the one hand, the delay of vessel arrival often occurs in the actual operation of the ports, and more than 40% of the international liners will be delayed at least one day [5]. On the other hand, the demand of maritime market has never been unchangeable, the global economic and trade, political environment and other factors have brought uncertainty to the maritime market. These uncertain events, not only made

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it difficult to determine the key parameters which are necessary for planning of berth allocation and quay crane assignment, but also lead to the baseline schedule cannot be implemented.

There are usually two strategies for coping with uncertainties: proactive and reactive strategy [6]. This paper covers both two strategies for the integrated optimization of BAP and QCAP under uncertainties. A stochastic programming model is formulated for minimizing the waiting time and delay of vessel departure. Besides, numerical experiments and scenario analysis are conducted to validate the effectiveness of the proposed model.

2 Related works

For the integration of BAP and QCAP (B&QCAP), there are many related works from different aspects, e.g. deterministic or uncertain, discrete or continuous berth, time-invariant or time variant QC assignment policy, maximizing handling efficiency or trade-off between efficiency and energy consumption, et al. In this section, we mainly reviews the studies which are highly related to the strategies for coping with the integration of BAP and QCAP under uncertainties.

Han et al. [7] studied integration of BAP and QCAP with uncertainty of container handling time and dynamic vessel arrival with different service priorities, a mixed integer programming (MIP) model is established, and a simulation based genetic algorithm search procedure is applied to generate a perturbation insensitive robust schedule proactively. Considering stochastic arrivals, Hendriks et al. [8] developed a MIP to construct a robust window-based cyclic berth plan with minimally required crane capacity in the worst vessel arrival scenario. Goliasa et al. [9] presented a mathematical model and a solution approach for the discrete berth scheduling problem, where vessel arrival and handling times are not known with certainty (given the lower and upper bounds). A robust berth schedule by minimizing the average and the range of the total service times required for serving all vessels was provided. Rodriguez-Molins et al. [10] introduced the robustness of B&QCAP by means of buffer times, which should be maximized to absorb possible incidences or break downs. To handle the uncertainty of QC productivity, the mean values of QCs were used by Shang et al. [11], and two robust models (robust optimization model and robust optimization model with price constraints) were proposed.

However, when disruptions occurred and the baseline schedule will no longer be the optimal solution, the reactive strategy should be implemented consequently. Zeng et al. [12] addressed the problem of recovering berth and quay crane schedule, the QC rescheduling strategy and berth reallocation strategy are proposed to tackle disruptions and recover the berth and QC schedule, and models for the two strategies are developed respectively. Li et al. [13] proposed a reactive recovery strategy which adjust the initial plan to handle realistic disruptions. The new berthing positions for vessels are restricted within a certain space. Quay cranes are allowed to move to other vessels before finishing current assigned vessels. Vessels requiring early dispatch are particularly considered in recovery planning. Four kinds of disruption, i.e., deviation of vessels' arrival times, deviation of vessels' operation times, calling of unscheduled vessels, and breakdown of QCs, were addressed by Xi et al. [14], and a reactive strategy was proposed, which takes the baseline schedule as the reference schedule, to deal with disruptions and minimize recovery cost. A rolling horizon heuristic is presented to derive good feasible solutions.

3 Model formulation

3.1 Notation definition

Sets and parameters: V represents the set of all vessels; T represents the set of all periods; Q represents the set of all QCs; B represents the total number of berth segments; Ω represents the set of all future scenarios; M represents a large positive number; ETA_i represents the estimated arrival time of vessel i; ETD_i represents the estimated departure of vessel i; R_i^{max} represents the maximum number of QCs that can be assigned to vessel i; R_i^{min} represents the minimum number of QCs that should be assigned to vessel i; m_i represents the handling volume of vessel i (units: TEU); b_i represents the desired berthing position of vessel i; γ_q represents the handling efficiency of a QC per unit time when q QCs simultaneously serve the same vessel (units: move/h); ξ represents the handling efficiency of a QC (units: h/move); μ represents the average value of containers where a QC handled per move (units: TEU/move); L represents the length of the wharf; l_i represents the length of vessel i, including horizontal safe distance; $p(w)$ represents the probability of scenario w; $ETA_i(w)$ represents the estimated arrival time of vessel i in scenario w; $ETD_i(w)$ represents the estimated finishing time of vessel i in scenario w; $R_i^{max}(w)$ represents the maximum number of QCs that can be assigned to vessel i in scenario w; $R_i^{min}(w)$ represents the minimum number of QCs that should be assigned to vessel i in scenario w; $m_i(w)$ represents the handling volume of vessel i in scenario w (units: TEU).

Decision variables: s_i represents the start berthing time of vessel i; y_i represents the actual berthing position of vessel i; e_i represents the end berthing time of vessel i; $s_i^+(w)$, $s_i^-(w)$ represent the increment and decrement of s_i in scenario w respectively; $y_i^+(w)$, $y_i^-(w)$ represent the increment and decrement of y_i in scenario w respectively; $e_i^+(w)$, $e_i^-(w)$ represent the increment and decrement of e_i in scenario w respectively; $s_i^{\Delta+}(w)$, $s_i^{\Delta-}(w)$ represent the increment and decrement with represent to $(s_i - \mathrm{EAT_i})$ in scenario w respectively; $y_i^{\Delta+}(w)$, $y_i^{\Delta-}(w)$ represent the increment (or decrement) with respect to $|y_i - \mathrm{b_i}|$ in scenario w respectively; $e_i^{\Delta+}(w)$, $e_i^{\Delta-}(w)$ represent the increment (or decrement) with respect to $(e_i - EFT_i)$ in scenario w respectively; $\triangle b_i$ represents the segment deviation of vessel i between the actual berthing position and preferred berthing position; $\triangle b_i(w)$ represents the segment deviation of vessel i between the actual berthing position and preferred berthing position in scenario ω ; X_{ij} is 0-1 decision variable, $X_{ij} = 1$, if Vessel i is located in the left of Vessel j in the 2-dimensional berth-time plane; $X_{ij} = 0$, otherwise; Y_{ij} is 0-1 decision variable, $Y_{ij} = 1$, if Vessel i is located below Vessel j in the 2-dimensional berth-time plane; $Y_{ij} = 0$, otherwise; $X_{ij}(w)$ is 0-1 decision variable, $X_{ij} = 1$, if Vessel i is located in the left of Vessel j in the 2-dimensional berth-time plane in scenario w; $X_{ij} = 0$, otherwise; $Y_{ij}(w)$ is 0-1 decision variable, $Y_{ij} = 1$, if Vessel i is located below Vessel j in the 2-dimensional berth-time plane in scenario w; $Y_{ij} = 0$, otherwise; r_{it} is 0-1 decision variable, $r_{it} = 1$, if at least one QC is assigned to vessel i in period t; $r_{it} = 0$, otherwise; $r_{it}(w)$ is 0-1 decision variable, $r_{it} = 1$, if at least one QC is assigned to vessel i in period t in scenario w; $r_{it} = 0$, otherwise; r_{itq} is 0-1 decision variable, $r_{itq} = 1$, if q QCs are assigned to vessel i in period t; $r_{itq}=0$, otherwise; $r_{itq}(w)$ is 0-1 decision variable, $r_{itq}=1$, if q QCs are assigned to vessel i in period t in scenario w; $r_{itq}=0$, otherwise.

3.2 Mathematical model

The objective function of the model is to minimize the sum of waiting time and delayed finishing time of baseline schedule and the expected value of the adjusting time in each scenarios.

$$\min f=\sum_{i=1}^{N}[(s_i-ETA_i)+(e_i-ETD_i)] + \sum_{w=1}^{W}\left\{p(w)\sum_{i=1}^{N}\left[\Delta s_i^{+}(w)-\Delta s_i^{-}(w)+\Delta e_i^{+}(w)-\Delta e_i^{-}(w)\right]\right\} \tag{1}$$

$$e_i\le s_j+M(1-X_{ij}),\ \ \forall i,j\in V, i\ne j \tag{2}$$

$$\mathrm{y}_i+l_i\le y_j+M(1-Y_{ij}),\ \ \forall i,j\in V, i\ne j \tag{3}$$

$$X_{ij}+Y_{ij}+X_{ji}+Y_{ji}\ge 1,\ \ \forall i,j\in V, i\ne j \tag{4}$$

$$y_i+l_i\le L,\ \ \forall i\in V \tag{5}$$

$$s_i\ge ETA_i,\ \ \forall i\in V \tag{6}$$

$$\sum_{i\in V}\sum_{q\notin Q} q\cdot\varphi_{itq}\le |Q|,\ \ \forall t\in T \tag{7}$$

$$\sum_{q\in Q} q\cdot\varphi_{itq}\le R_i^{\max}\cdot\zeta_{it},\ \ \forall i\in V, t\in T \tag{8}$$

$$\sum_{q\in Q} q\cdot\varphi_{itq}\ge R_i^{\min}\cdot\zeta_{it},\ \ \forall i\in V, t\in T \tag{9}$$

$$\sum_{q\in Q}\varphi_{itq}=\zeta_{it},\ \ \forall i\in V, t\in T \tag{10}$$

$$\zeta_{it}\cdot(t+1)\le e_i,\ \ \forall i\in V, t\in T \tag{11}$$

$$\zeta_{it}\cdot t+M\cdot(1-\zeta_{it})\ge s_i,\ \ \forall i\in V, t\in T \tag{12}$$

$$\sum_{k=1}^{B}\Delta b_{ik}\cdot k\ge |y_i-b_i|,\ \ \forall i\in V \tag{13}$$

$$\sum_{k=1}^{B}\Delta b_{ik}\le 1,\ \ \forall i\in V \tag{14}$$

$$\sum_{t\in T}\sum_{q\in Q} q\cdot\varphi_{itq}\cdot\gamma_q\ge\frac{m_i}{\mu}\cdot\Delta b_i^{0.14},\quad \forall i\in V \tag{15}$$

$$\sum_{t\in T}\sum_{q\notin Q} q\cdot\varphi_{itq}\cdot\gamma_q\ge\frac{m_i}{\mu},\ \ \forall i\in V \tag{16}$$

$$\sum_{t\in T}\zeta_{it}=e_i-s_i,\ \ \forall i\in V \tag{17}$$

$$e_i + e_i^+(w) - e_i^-(w) \le s_j + s_j^+(w) - s_j^-(w) + M\left[1 - X_{ij}(w)\right], \quad \forall i, j \in V, i \ne j, w \in \Omega \tag{18}$$

$$y_i + y_i^+(w) - y_i^-(w) + l_i \le y_j + y_j^+(w) - y_j^-(w) + M\left[1 - Y_{ij}(w)\right], \quad \forall i, j \in V, i \ne j, w \in \Omega \tag{19}$$

$$X_{ij}(w) + Y_{ij}(w) + X_{ji}(w) + Y_{ji}(w) \ge 1, \quad \forall i, j \in V, i \ne j, w \in \Omega \tag{20}$$

$$l_i \le y_i + y_i^+(w) - y_i^-(w) + l_i \le L, \quad \forall i \in V, w \in \Omega \tag{21}$$

$$s_i + s_i^+(w) - s_i^-(w) \ge ETA_i(w), \quad \forall i \in V, w \in \Omega \tag{22}$$

$$s_i - ETA_i + \Delta s_i^+(w) - \Delta s_i^-(w) = s_i + s_i^+(w) - s_i^-(w) - ETA_i(w), \quad \forall i \in V, w \in \Omega \tag{23}$$

$$\left|y_i - b_i\right| + \Delta y_i^+(w) - \Delta y_i^-(w) = \left|y_i + y_i^+(w) - y_i^-(w) - b_i\right|, \quad \forall i \in V, w \in \Omega \tag{24}$$

$$e_i - ETD_i + \Delta e_i^+(w) - \Delta e_i^-(w) = e_i + e_i^+(w) - e_i^-(w) - ETD_i(w), \quad \forall i \in V, w \in \Omega \tag{25}$$

$$\sum\nolimits_{i \in V} \sum\nolimits_{q \notin Q} q \cdot \varphi_{itq}(w) \le |Q|, \quad \forall t \in T, w \in \Omega \tag{26}$$

$$\sum\nolimits_{q \in Q} q \cdot \varphi_{itq}(w) \le R_i^{\max}(w) \cdot \zeta_{it}(w), \quad \forall i \in V, t \in T, w \in \Omega \tag{27}$$

$$\sum\nolimits_{q \in Q} q \cdot \varphi_{itq}(w) \ge R_i^{\min}(w) \cdot \zeta_{it}(w), \quad \forall i \in V, t \in T, w \in \Omega \tag{28}$$

$$\sum\nolimits_{q \in Q} \varphi_{itq}(w) = \zeta_{it}(w), \quad \forall i \in V, t \in T, w \in \Omega \tag{29}$$

$$\zeta_{it}(w) \cdot (t+1) \le e_i(w) + e_i^+(w) - e_i^-(w), \quad \forall i \in V, t \in T, w \in \Omega \tag{30}$$

$$\zeta_{it}(w) \cdot t + M \cdot \left[1 - \zeta_{it}(w)\right] \ge s_i + s_i^+(w) - s_i^-(w), \quad \forall i \in V, t \in T, w \in \Omega \tag{31}$$

$$\sum\nolimits_{k=1}^{B} \Delta b_{ik}(w) \cdot k \ge \left|y_i(w) + y_i^+(w) - y_i^-(w) - b_i\right|, \quad i \in V, w \in \Omega \tag{32}$$

$$\sum\nolimits_{k=1}^{B} \Delta b_{ik}(w) \le 1, \quad i \in V, w \in \Omega \tag{33}$$

$$\sum_{t \in T} \sum_{q \in Q} q \cdot \varphi_{itq}(\omega) \cdot \gamma_q \ge \Delta b_i(\omega)^{0.14} \frac{m_i(\omega)}{\mu}, \quad i \in V, \omega \in \Omega \tag{34}$$

$$\sum\nolimits_{t \in T} \sum\nolimits_{q \notin Q} q \cdot \varphi_{itq}(w) \cdot \gamma_q \ge \frac{m_i(w)}{\mu}, \quad i \in V, w \in \Omega \tag{35}$$

$$\sum\nolimits_{t \in T} \zeta_{it}(w) = e_i + e_i^+(w) - e_i^-(w) - \left[s_i + s_i^+(w) - s_i^-(w)\right], \quad \forall i \in V, w \in \Omega \tag{36}$$

$$\Delta b_i = \left|y_i - b_i\right| / L_s, \quad \forall i \in V \tag{37}$$

$$X_{ij}, Y_{ij}, X_{ij}(w), Y_{ij}(w) \in \{0,1\}, \quad \forall i, j \in V, w \in \Omega \tag{38}$$

$$\zeta_{it}, \varphi_{itq}, \zeta_{it}(w), \varphi_{itq}(w) \in \{0,1\}, \quad \forall i \in V, t \in T, q \in Q, w \in \Omega \tag{39}$$

$$\Delta b_i, \Delta b_i(w) \in \{0,1\}, \quad \forall i \in V, w \in \Omega \tag{40}$$

$$s_i(w), s_i^+(w), s_i^-(w), e_i(w), e_i^+(w), e_i^-(w) \geq 0, \quad \forall i \in V, w \in \Omega \tag{41}$$

$$\Delta s_i^+(w), \Delta s_i^-(w), \Delta e_i^+(w), \Delta e_i^-(w), y_i \geq 0, \quad \forall i \in V, w \in \Omega \tag{42}$$

Constraints (2)-(3) define the berth position and order of any two vessels. Constraint (4) ensures there is no overlap among all vessels in the 2-dimensional berth-time plane. Constraint (5) ensures the positions of all vessels are restricted by the length of the terminal. Constraint (6) implies that the start berthing time cannot earlier than the expected arrival time. Constraint (7) ensures that the number of QCs assigned to all vessels cannot exceed the total number of available QCs in any time segments. Constraints (8)-(9) ensure that the number of QCs assigned to a vessel must not be greater than the maximum number of QCs allowed to serve simultaneously, and not be smaller than the minimum number of QCs should be assigned. Constraint (10) determines the relationship between r_{itq} and r_{it}. Constraint (11) ensures that there is no QC assigned to vessel i after it departs. Constraint (12) ensures that there is no QC is assigned to vessel i before it arrives. Constraints (13) defines the number of berth deviation segments of vessel i. Constraint (14) ensures that the number of berth deviation segments of vessel i takes only one specific value. Constraints (15) ensure that QC assignments for a vessel must satisfy the vessel's real QC hours demand considering the QCs' idle times as the result of berthing deviation. Constraint (16) ensures that QC assignments for a vessel must satisfy the vessel's QC hours demand without the berthing deviation. Constraint (17) determines the relationship between the handling time and the start berthing time or the end berthing time. Constraints (18)-(19) define the berth position and order of any two vessels after adjusting vessels' schedules. Constraint (20) implies there is no overlap among all vessels in the 2-dimensional berth-time plane after adjusting vessels' schedules. Constraint (21) ensures the positions of all vessels are restricted by the length of the terminal in varied scenario. Constraint (22) implies that the newly planned start berthing time cannot earlier than the expected arrival time. Constraint (23) builds the relationship between the adjustments of start berthing time ($s_i^+(w), s_i^-(w)$) and the change of waiting time ($s_i^{\Delta+}(w), s_i^{\Delta-}(w)$). Constraint (24) builds the relationship between the adjustments of actual berthing position ($y_i^+(w), y_i^-(w)$)) and the change of deviation from the best berthing position ($y_i^{\Delta+}(w), y_i^{\Delta-}(w)$). Constraint (25) builds the relationship between the adjustments of end berthing time ($e_i^+(w), e_i^-(w)$) and the change of delayed finishing time ($e_i^{\Delta+}(w), e_i^{\Delta-}(w)$). Constraint (26)-(27) ensure that the newly planned number of QCs assigned to a vessel must not be greater than the maximum number and not be smaller than the minimum number of QCs should be assigned. Constraint (28) ensures that the newly planned number of QCs assigned to all vessels cannot exceed the total number of available QCs in any time segments. Constraint (29) determines the relationship between $r_{itq}(w)$ and $r_{it}(w)$. Constraint (30) ensures that there is no QC assigned to vessel i after it departs. Constraint (31) ensures that there is no QC assigned to vessel i before it arrives. Constraint (32) defines the newly planned number of berth deviation segments of vessel i. Constraint (33) ensures that the newly planned number of berth deviation segments of vessel i takes only one specific value. Constraint (34) ensure that QC assignments for a vessel must satisfy the vessel's real QC hours demand considering berthing deviation in varied scenario. Constraint (35) ensures that QC assignments for a vessel must satisfy the vessel's QC hours demand without the berthing deviation in varied scenario. Constraint (36) determines the relationship between handling time and newly planned actual start berthing time or actual end berthing time. Constraints (37) calculates the deviation of berthing position. (38)-(42) define the integer or binary variables.

4 Numerical experiments

To verify the effectiveness of the proposed model, we compare the results between the proposed model (M1) and the traditional model (M2), which only the proactive strategy is used (the recovery schedule is not included). Table 1 and Table 2 are the comparison results with vessels delay and containers increased respectively, and it shown that the proposed model has a better efficiency to deal with uncertainties.

Table 1. Results with vessels delay.

$\|V\|$	$\|\Omega\|$	Delayed Vessels	Delay time	M1	M2	$GAP(\%)$
8	5	1	1 h	390	450	15.38
8	5	2	1 h	420	480	14.29
8	5	3	1 h	450	510	13.33
8	5	1	2 h	420	480	14.29
8	5	2	2 h	480	540	12.50
8	5	3	2 h	540	600	11.11
8	5	1	3 h	450	510	13.33
8	5	2	3 h	540	600	11.11
8	5	3	3 h	630	690	9.52

Table 2. Results with vessel containers increased.

$\|V\|$	$\|\Omega\|$	Altered Vessels	Altered volume	M1	M2	$GAP(\%)$
8	5	0.10	40	360	420	16.67
8	5	0.10	40	360	420	16.67
8	5	0.10	40	360	420	16.67
8	5	0.10	80	372	432	16.13
8	5	0.10	80	378	438	15.87
8	5	0.10	80	402	462	14.93
8	5	0.10	120	390	450	15.38
8	5	0.10	120	426	486	14.08
8	5	0.10	120	450	510	13.33

5 Conclusions

This paper studied the integrated optimization of BAP and QCAP under uncertainties. A stochastic programming model is formulated for minimizing the waiting time and delay departure time of vessels. Besides, numerical experiments and scenario analysis are conducted to validate the effectiveness of the proposed model. The results can help port operators to generate a better schedule for dealing with the impact of various uncertainties. Furthermore, it will improve operational efficiency, reduce operating costs and bring economic benefit to terminal operators. However, there are still some limitations in this paper. For example, the increase of uncertain parameters will increase the scale of the experiment in geometric series. The scale of the experiment is also limited to small-scale experiments. In addition to the above factors, we will concern the impact of the probability fluctuation of the scene on the plan as well in the future.

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From Control to Coordination: Mahalanobis Distance – Pattern Approach to Strategic Decision Making

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Abstract. Up to now, our engineering has been control-based. The goal was clear, We made efforts to get to the goal faster and more effectively. This was possible because changes were smooth, so we could differentiate them mathematically. Therefore, we could predict the future. But today, changes become sharp and unpredictable. Therefore, adaptability becomes more important than efficiency. Or to describe it another way, we need to find an appropriate goal first by trial and error. Yesterday tactics was important, but today strategy becomes important. But our world becomes so complex and complicated that we need to work as a team. And the formation of this team must vary from situation to situation to win the game. Therefore, we must develop a truly adaptive network. This paper proposes that if we introduce non-Euclidean Mahalanobis Distance (MD) and combine it with patterns, then we can develop a holistic and quantitative performance indicator. It evaluates our performance in a very short time for almost any number of dimensions, because it is free from the constraints of orthonormality and units in Euclidean Space. Thus, this Mahalanobis Distance-Pattern (MDP) Approach helps us to make an approriate strategic decision.

Keywords. Strategic Decision Making, Unpredictable Changes, Control, Coordination, Management, How to Win the Game, Self-Decision, Psychological Satisfaction and Happiness

1. Introduction

This paper points out how the real world is changing. Although there were changes yesterday, they changed smoothly, so we could predict the future. Thus, the idea of *Control* played a leading role. Therefore, we evaluated product value and tactics was important. *Reproducibility* and *Rationality* were key ideas. But today, the real world changes frequently and extensively and what makes it worse, in an unpredicable manner. Thus, the word *Adaptability* is attracting wide attention. But if we wish to make our dreams come true, we need to outsmart the environments and situations.

To solve this problem, we need to work together with machines (robots) on the same team, as IoT indicates. To work as a human-machine team to cope flexibily and adaptively with drastic changes, we need to be in the system. We used to give instruction to muchines from outside and machines followed. But to effectively and adaptively respond to the changes, we need a communication tool and we need a performance indicator to know how well we are doing. As to communication, *Movements* are a common basis for machines and humans. But current researches on movements are based on the idea of Control. When the environments and situations change rapidly, we need Coordination. In fact, humans coordinate many body parts and balance our bodies. In short, our world is changing from *Tactics* to *Strategy* and what and how decisions should be done become crucially important.

This paper proposes *Mahalanobis Distance Pattern (MDP) Approach* for supporting *Strategic Decision Making* and as the number of degrees of freedom becomes tremendously large, we leave the decision to our *Instinct*, because the direct interaction with the real world becomes indispensable and to avoid computational complexity, we can utilize our *Instinct* as the octopus is doing. *MDP* helps us to perceive the real world and provide the holistic and quantitative performance indicator to move in the adequate way and in our own personal way.

The main core of this paper is since the Industrial Revolution, we have been working for others. i.e., for external rewards, but in the next generation engineering, working for your own *Self* becomes crucially important. In short, our engineering will change from material satisfaction to mental satisfaction. *MDP* will enable us to enjoy mental satisfaction and happiness.

2. From Control to Coordination

Importance of *Coordination* is rapidly increasing. Up to now, engineering has focused on *Control*. This is because changes yesterday were smooth, so we could differentiate them mathematically. In other words, we could predict the future. Thus, engineers could foretell the operating conditions of their products. Therefore, their focus has been on products and on how they could control them.

But today the changes are sharp. Therefore, we cannot predict the future. Engineers cannot estimate the operating conditions of their products anymore (Figure 1).

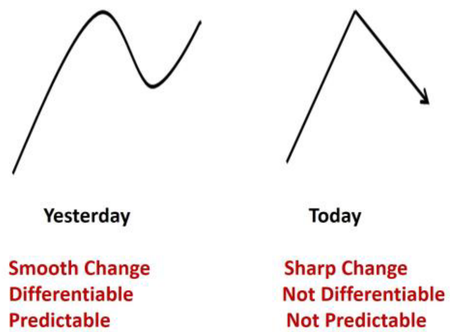

Figure 1. Changes of yesterday and today.

And our world keeps on expanding rapidly and changed from a small, closed world with boundaries to a wide, open world without boundaries. Such changes make it very difficult to apply rational approaches. Therefore, *Coordination* or *Strategic Management* is increasing its imporance. But we do not have good tools for esttimating our performance.

Why we have difficulty in making adequate decisions to cope with the changing situations is because we have been stuck with *Euclidean Space* approaches. If we introduce *Non-Euclidean Space* approach, we can free ourselves from the constraints of orthonormality and units and expand dimensions easily. *Mahalanobis Distance (MD)* is one of such *Non-Euclidean* tools.

This paper points out that if we introduce *MD* and combine it with *Patterns*, we can evaluate our *Strategic Decision Making* performance holistically and quantitatively.

3. The Real World is Changing from Predictable to Unpredictable

When our world was closed with boundaries, we could apply rational approaches in a straightforward way. But as our world changed to wide, open without boundaries and the changes become unpredictable, we cannot apply rational approaches anymore.

4. System Identification Approach: Expanding Rational World to Controllable World

To cope with this problem, engineers invented *System Identification Approach*, Its basic idea is the same as the one we use to indentify the name of a river. If we look at the river (flow) itself, we cannot identify its name, because it changes every minute. But if we look around, we can find mountains or forests that do not change. So, we can identify its name (Figure 2).

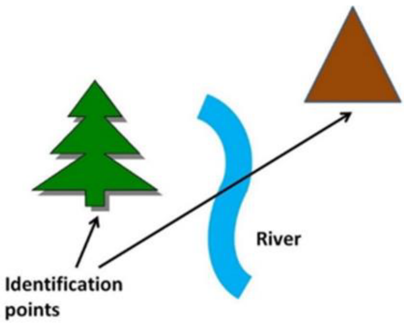

Figure 2. Identifying the name of a river.

System Identification Approach pays attention to such feature points to identify the system. Once the system is identified, we can identify its parameters. Thus, we succeeded in expanding the *Rational World* and established the *Controllable World*.

But as changes take place more and more frequently and extensively, and in an unpredictable manner, *System Identification Approach* does not work anymore.

In short, we have been discussing on the bank of a river, but we are now thrown into the river. So, we need to swim against the flow to get to the goal we have on our mind. Strictly speaking, the word *Adaptability* is not appropriate. If we only adapt to the flow, we will be carried away and we cannot get to our goal. We need to overcome the flow to get to the goal. It is nothing else but a game and we need to win the game against the enemy, i.e., the changing real world.

Then, how can we overcome the environment and situation and get to where we want to? As *Movement* is essential in product performance, let us take up here *Human Movement* to understand why *Coordination* becomes more important than *Control.*

5. Human Movement

Nikolai Berstein, famous human motion control researcher, showed us how *Human Movement* trajectories vary widely [1],[2], (Figure 3).

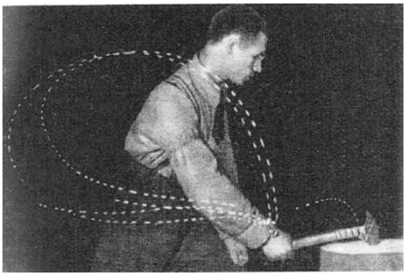

Figure 3. Cyclogram of hammering.

But such variations are observed only at the early stage. When we get close to the target object, our trajectories are fixed. Almost all motion studies or robotics deal with this stage. At this stage, the number of degrees of freedom is reduced to the minimum and as the trajectories are fixed, we can apply rational approaches. In other words, we can *Control* them.

Then, why do our trajectories vary so widely from situation to situation at the early stage? It is because we, humans, *Coordinate* many body parts and *Balance* our body.

There are two kinds of *Humna Movements*. *Motion* is movement we observe from the outside. *Motor* is within ourselves. *Motion* is made clear as Bernstein showed us using his cyclogram. But as to *Motor*, almost all is still unclear, although particular research is being carried out, We do not know anything about it as a whole.

Bernstein pointed out that the problem of tremendously large number of degrees of freedom makes the study of *Human Movement* very difficult and that it is not *Control*, but *Coordination* which we should consider to study *Human Movement*.

In fact, at the early stage when our trajectories vary widely, many different *Muslces* are mobilized. Which *Muscles* are mobilized varies from case to case. But when we get close to the target obect, *Muscles* harden and we do not need to consider *Muscle Movements* at all. They move together with our *Skeleton.* Thus, almost all *Motion Control* studies are based on *Skeleton Movements*. They do not consider *Muscle Movements.* But at the early stage, *Muscles* work from one muscle to another. Many different *Muscles* work in response to the changing situation. We, humans, use many different parts of our body to respond to the changing environment and situation.

6. Increasing Importance of Strategic Decision Making: Five Sectors of the Economy

Interestingly enoough, economists are proposing the quinary sector of the economy. The primary sector is agriculture, fishing, hunting, etc. The secondary sector is manufaturing, etc. The tertial sector is service industry. The quaternary sector is ICT. These are well-known.

The quinary sector is *Decision Making*. Economists point out that what tools we use and what pieces of information we use become increasingly important. Thus, they insist *Decision Making* will be the next sector of the economy（Table 1）.

Table 1. Five sectors of the economy.

Sector	Activities
5 Quinary Sector	Decision Making
4 Quaternary Sector	Knowledge and ICT Industry
3 Tertiary Sector	Service Industry
2 Secondary Sector	Transforms raw materials into Products – Manufacturing, etc.
1 Primary Sector	Extracts raw materials from nature – Agriculture, Fishing, etc.

7. Team Formation Cooresponding to the Changing Situation

Then, how can we make right decisions in engineering today, when environments and situations change frequently, extensively and in an unpredictable manner?

As three heads are better than one, we need a team to cope with this problem. And this team should be a network, because all nodes in a network can be an output node so that flexible response can be secured. But we need more than that. We need a network that changes flexibly with the changes of the real world.

If we take up soccer, I think we can understand easily. Its formation yesterday did not change. All players are expected to do his best at his own position, because the game did not change much. But today, the game changes frequently and extensively and you cannot predict what strategy your enemy will take. So, you must change your formation very flexibly and adaptively to win the game.

Managers were outside of the pitch yesterday, but today they are on the pitch. In most cases, midfielders are playing-managers. And other players must be prepared proactively to respond to his instructions. The formation changes drastically. It may be 3 player or 4 player formation, depending on the situation and other playes must be prepared in advance to form such game-winning formation. Thus, *Coordination* becomes crucial in soccer. Which players to use or what formation to take. We must make decisions.

8. How Can We Coordinate? It Requires Trials and Errors.

But such *Coordination* is carried out by trial and error. In short, *Coordinaion* requires *Pragmatic Approach*. *Learning from Failures* is emphasized in *Pragmatism*. But there is no appropriate tool to assist us with the task how to practice it. This is because appropriate performance indicators are lacking.

In engineering, we use *Euclidean Space* tools in most cases. But *Euclidean Space* reequires orthonormality and units. So with increasing dimensionality, *Euclidean Space* approach becomes increasingly difficult to apply.

9. Mahalanobis Distance (MD)

But if we introduce *Non-Euclidean Space* tool, then we can free ourselves from the constraints of orthonormality and units. *Mahalanobis Distance* is originally proposed to identify the outliers. It indicates how much the point P is far away from the mean of the dataset. Note that this dataset can be any dataset. It does not have to be normally distributed (Figure 4).

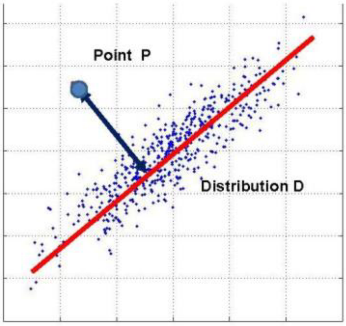

Figure 4. Mahalanobis Distance (MD).

Mahalanbis Distance (MD) is defined as

MD = (Standard deviation)/(mean)

So, *MD* is not a distance in the sense of *Euclidean Space*. It is a quotient.
And each *MD* is independent. No orthogonality is required. So, we can increase dimensionality easily.

But to understand the whole picture, we need to know how each *MD* is related. Introduction of *Patterns* enables us to do such a holistic performance evaluation. Thus, if we combine *MD* and *Patterns*, we can develop a holistic and quantitative performance indicator.

10. Patterns: Its Advantage

Fukuda and his group used to study how we can extract emotion from face. They tried many image processing technques, but these techniques took too much time and without any satisfying results.

While repeating such trials, Fukuda realized we can extract emotion from the cartoon face without any difficulty. At that time, cartoons were in black and white and were very simple. Still, we could understand the emotion of characters at once.

So, his group developed cartoon face model and instead of processing images, they compared the real face with the cartoon face model and extracted emotion from face very easily [4], [5], (Figure 5).

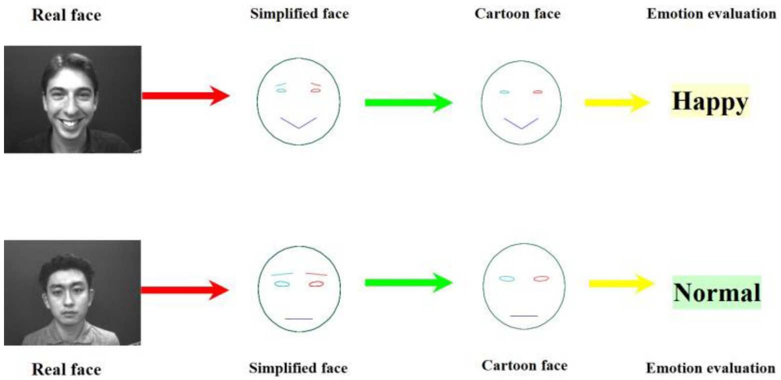

Figure 5. Cartoon Face Model.

In this study, comparison between the real face and the cartoon face was carried out, based on *Euclidean Space* approach. But the number of dimensions is very small, so it did not produce any problem at all.

But when the dimensions come to be very large, such *Euclidean Space* approach does not work effectively. But if we introduce *MD* and combine it with *Patterns*, then we can understand easily how better or worse we are performing.

11. Mahalanobis Taguchi System (MTS)

Genichi Taguchi developed *Mahalanobis Taguchi System (MTS)* [6] about the same time. We should note that *MTS* is completely different from well-known Taguchi Method (TM). TM controls quality element by element or part by part and it is based on *Eulidean Space* approach. But *MTS* is factory-based holistic Quality Management. It is not *Control*, but *Coordination*. Different sectors of a factory work collaboratively to achieve the desired quality of a final product.

Taguchi realized that if he introduces *MD* to quality management, such factories which cannot control quality part by part can manage quality as a factory. *MD* is free from orthonormality and units, so they can apply easily. But they cannot evaluate how good they are doing as a whole. Taguchi realized that if he combines *MD* with *Patterns*, then they can see the whole picture.

MTS goes in the following way. Let us take number example here. Number 2 is written in many different ways from person to person. But if we average those which can be identified as number 2, we can get a standardized number 2 (Figure 6). We call this standardarized number 2 Unit Space.

Figure 6. Defining Unit Space.

Then we set the allowable threshold (Figure 7), If *MD* is smaller than this threshold, the number can be identified as number 2. If *MD* is larger than the threshold, we cannot regard it as number 2.

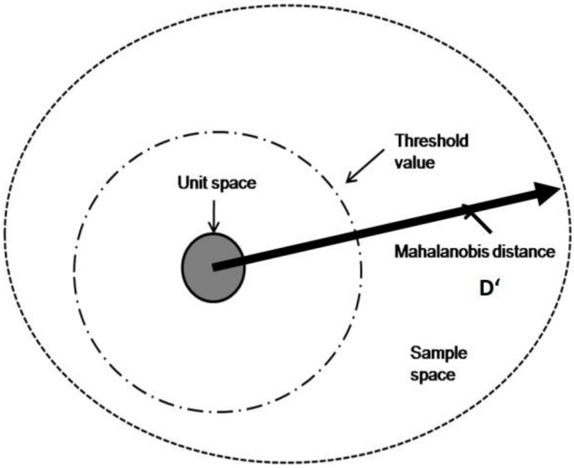

Figure 7. Mahalanobis Taguchi System (MTS).

We should note that images can be processed in the same way, because images are represented as pixel sequence (Figure 8). So, it boils down to patterns.

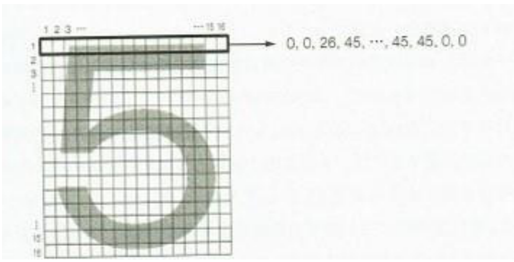

Figure 8. Pixels to pattern.

MTS is welcomed by many companies. These companies cannot carry out part by part quality control. But they can manage quality holistically or on a factory basis.

12. Mahalanobis Distance–Pattern (MDP) Approach

The merit of *MTS* is factories can perform *Strategic Decision Making*. Other quality tools are control-based or tactics-based. Its merit is the goal is clear from the first, so factroies can make efforts to reduce time and cost.

But today environments and situations change frequently and extensively, and in an unpredicable manner so it becomes more and more diffiulct for factories to identify what element or part to control. Many different sectors share the same problem. So, it is pointed out widely that *Adaptability* is becoming more important than *Control*. But *Adaptability* is not enough. What we should pursue is to overcome the situation.

Thus, *MTS* is very useful, because industries do not have to find paratmeters to control. This is why *System Identification Approach* is no more effective.

MDP Approach measures "***how performance changes with each movement".*** The decision is left to humans, or to be exact, it is *Instinct.* Utilizing *Instinct,* we can judge if we are doing better or worse. So, we can improve our performance by introducing *MDP Approach* to help our *Instinctive Cognition*.

This is the greatest difference between *MTS* and *MDP Approach*. *MTS* is a static pattern identification, But *MDP Approach* is a management tool to win the game, utlizing our *Instinct Judgement*. The greatest difference between *MTS* and *MDP Approach* is *MDP* is a tool for *Learning from Failures*. We try one way and if it does not work, we will try another.

13. Applications

As everybody knows, there are no robots which can learn to swim by themselves. There are robots which can swim, but if the current changes, they cannot adapt to them. To my knowledge, no robots are developed which can learn to swim and which can swim against the flow to get to the goal, no matter how the flow might change. *MDP Approach* provides us with a support to win such a game.

Therefore, we can develop *Wearable Robots*, which can learn how to win the game by trial and error. So, if we put *Wearable Robots* on and work together, we can learn to swim our own way. As our body builds are different, how we learn to swim or move varies from person to person, or from situation to situation. And such *Wearable Robots* will assist seniors to move their own way. And they will facilitate *Rehabiliation Customization.* Current rehabilitation is trying to get the handicapped back to the non-handicapped day conditions. For example, if we put on prostheses, then it is a combination of artificial thing and our natural thing (body). So, the movement should be different. We should develop walking or grasping style for the handicapped to enjoy their own way.

14. Direct Interaction with the Real World: Learning from the Octopus

The real world is changing frequently, extensively and in an unpredicable manner. So, we need to directly interact with the real world. In addition, materials are gettting softer and softer, so that vision alone cannot identify the object. We need to directly interact with the object. That is why haptics or sense of touching is getting importance.

This is what the octopuses are doing. They die immendiately after their babies are born. So, they do not inherit knowledge from the previous generations. They live on their instinct alone. But they are known as the expert of escape and they can escape from any environments and situations. They directly interact with the real world. That is why they can. *MDP Approach* helps us to make the most of our *instincts* to perceive and make appropriate decisions.

15. Summary

As Abraham Maslow pointed out in his hierarchy of human needs [7], the highest need of us, humans, is *Self-Actualization*. And Edward Deci and Richard Ryan proposed

Self-Determination Theory and they pointed out if the work is intrinsically motivated and self-determined, we will have the greatest mental satisfaction and happiness. They also pointed out that growth is important human need [8]. But they did not tell us how. Therefore, *Mahalanobis Distance-Pattern Approach* is proposed for holistic and qunatitative performance indicator to help us evaluate our performance.

what is unique with *MDP Approach* is the fiollowing.

To avoid computation complexity, it depends on our *Instinct*, just the same way as the octopus interacts with the real world directly and make decisions based on their *Instinct.*

Jean Piaget pointed out in his Theory of Cognitive Development that babies directly interact with the real world and they learn to grow. Until two years old, they move around and interact directly with the real world to learn and grow[9].

MDP Approach may be described as a tool for grownups to learn the same way as babies do or as the octopuses do. It should also be added that even when we say "I can swim". It means different things for different people. Some just float in the water, Others swim beautifully ahead. But both styles are "I can swim". Thus, up to now, we made efforts to be objective, but our styles of movement and decsion making vary widely from person to person. Our body builds and *Instinct* are different from person to person. Thus, *MDP Approach* is developed to be subjective for us to enjoy our *Self.*

Therefore, Emotional Engineering plays an important role for motivating us to challenge such issues and for bringing us with psychological satisfaction and happiness [10],[11],[12].

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Stamping Tools for Sheet Metal Forming: Current State and Future Research Directions

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Abstract. Sheet metal forming tools play an important role in the manufacturing of many products. With shorter product life cycles and demand for shorter time to market for new products, the process for design and manufacturing of stamping tools becomes a critical part. Stamping dies are often designed and manufactured by smaller, specialized companies. For a tooling company, knowledge and experience is an important competitive advantage. Traditionally the design process has been characterized by being based on few key individuals with much experience and craftsmanship. To stay competitive in this market there is a need for more efficient processes, systems, tools and supports in order to become more industrialized. This paper presents results from a study of the state of practice in industry within progressive stamping tool design as well as a review of relevant literature. The design and manufacturing processes for stamping dies in six companies have been investigated through semi-structured interviews, from which the main challenges in the current state for the companies are identified. The results from the interviews was analyzed and compared to the established concepts and frameworks of methods found in the literature review. The results and analysis points in the direction of efforts needed in supporting the formalization and reuse of information and knowledge from previous tool projects and production, especially during the critical steps of tool process planning and creating the tool layout.

Keywords. Sheet metal forming, Stamping, Dye design, State of practice, State-of-the-art

Introduction

Sheet metal forming (SMF) tools play an important role in the manufacturing of many products. The design of the tool affects the component properties, production rate, material utilization, post processing, quality and rejection rates. Tool design and manufacturing are often carried out by smaller and more specialized companies who delivers a complete tool ready for production of a sheet metal component. The component is often designed by larger companies, original equipment manufacturers (OEM), while the actual manufacturing of the component can be done by a sub-supplier. Customization is becoming more important for companies for delivering higher customer value and getting more efficient resource utilization in products. With higher product variety, that results in lower production volumes per tool. But stamping

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tools for SMF are quite expensive and require large volumes to be an economically good choice. OEMs demand shorter lead times to be able to have a shorter time to market. At the same time, there is a need to be able to quickly adapt to new requirements and customizations that can appear late in the product development process. Another aspect to this is that the adoption of the concurrent engineering paradigm has the consequence that tool design starts with uncertain or incomplete information and changes are to be expected [1]. In a competitive and global market, tooling companies submits quotations on numerous requests annually. To stay competitive in this market and enable higher product variety, there is a need for more efficient processes, systems, tools and supports to become more industrialized and enable companies to improve their ability to introduce new technology.

This paper presents results from the first part of a research project that is aimed at addressing challenges in designing SMF tools. The project uses the design research methodology (DRM) [2] and the study described here is part of the research clarification step. It is important to first understand the environment that improvements are to be implemented in. The first step in the project is therefore, to map the state of practice and identify the main challenges from the perspective of the tool designers. Some shorter, general descriptions of the tool design process can be found in various handbooks [3] but give little insight to the current state of practice. Also, traditionally the process of designing and manufacturing SMF tools has been characterized by being based on few key individuals with much experience, and craftsmanship. In this study, tool designers at six companies have been interviewed to get their qualitative view on what their process of tool design looks like, what design supports are used, how time and cost are distributed in the process and what their main challenges are. To be able to identify challenges and address them, the focus in this work is more on closer collaboration with the companies to get a more in-depth view, rather than broad.

In the following sections a review of relevant literature is made to overview the state-of -the-art for methods and supports in tool design. This is followed by the results from the interviews and an analysis comparing findings from the interviews with existing research from the literature review. Lastly the conclusions and a summation of future research directions and areas is made.

1. Review of the literature

The review of the literature was broken down in four sections: Design automation Simulation and material science and Platform approaches. Additionally a summary of the review performed by Kolhatkar and Pandey [4] on use of sensor technology and online monitoring in sheet metal tooling is found in the last section.

1.1. Design Automation

There have been many different attempts to automate the design of progressive dies for sheet metal stamping. Kumar and Singh [5] developed a knowledge-based system (KBS) for assisting the tool designer and automating parts of the process. Their system is implemented in AutoCAD and structured in different modules. The modules serve different purposes and solve problems using different methods. During the use of these modules different tasks are carried out. These are: flattening of the sheet metal part, nesting (to minimize scrap and balance the punch forces), creating the punch shapes, creating the bending die shapes, sequencing the punching and bending operations, deciding how and where pilots should be used, making the process plan including idle stations, detail design of all components of the tool, choose proper material for parts.

Different methods, systems and algorithms have been developed by researchers to automate or optimize the results of some of these tasks. Most commercial CAD-systems are able to flatten shapes based on developable surfaces. And some can flatten more complex shapes. Automatic nesting and piloting have been done in [6] and later in [7]. Their nesting algorithms are similar in that they are both placing two copies of the flattened shape next to each other and rotate the shapes in small increments and identifies eventual collisions and repositions the parts. Then for each rotation increment the scrap rate is calculated and lastly the angle with the minimum scrap is chosen. Notable here is that there are other criteria besides scrap that are of interest for optimizing towards, for example force balance of the punch and bending operations. But these are not considered. The pilot selection has different approaches as the algorithm [6] gives the designer areas where direct, indirect or semi-direct pilots could be placed and the approach in [7] can give specific points for were to place the pilots.

Sequencing of operations in the progressive die have been approached from different angels. Li et al. [8] developed a system that identifies bends from a CAD-model and uses case-based reasoning to determine the best bending sequence. Abedini et al. [9] automated the sequencing of bending operations with fuzzy set theory and later a system for sequencing punching operations with a main set partitioning (MSP) was suggested [10] where the punches are partitioned into the stations of the die with the help of priority sequences that the designer has to provide. Lin and Sheu [11] developed a method for sequencing of punches using clustering of punches to do a modified exhaustive search and then scoring of the variants. This was then used in [12] to make the complete layout planning of both punching and bending operations. According to Moghaddam et al. [13] the previous work on sequencing had not taken simultaneous operations and tolerances of specific features into account in a good enough way. So, they continued developing the system already developed in [14] that did the sequencing of both bending and punching using fuzzy set theory.

1.2. Simulation and analysis

In simulating and predicting formability, springback, wear, etc. many commercial software are readily availible such as AutoForm, PAM-STAMP and many other. The recent research in the area is focused on solving some specific challenges in the process. Pilthammar et al. [15] suggests a method for considering the elastic deformations of dies in order to get more accurate pressure distributions for the friction model and shape predictions i.e. draw-in and strains. This is done by first carrying out a structural FE-simulation of the tool and then transferring the deformed die shapes to the sheet metal forming simulation. The use of sub-modelling is recommended as the way to transfer the deformed shapes. To increase the accuracy of springback analysis without greatly increasing the solution time of the FE-models, Iwata and Iwata [16] proposed a method where a refined model of the drawbead and die shoulder is made separately and the results saved in a database. The data is then combined with the results of a conventional forming analysis and used to get a more accurate springback analysis.

Much research has been done within the area of optimization for the dies in SFM. Karen et al. [17] also recognizes that the deflections of the die as well as the press table are important to consider. To optimize the structure of the die in an efficient way they developed a new optimization algorithm where they enhanced the differential evolution method by using the best vectors as differential vectors, thus shortening the solution time. The use of load mapping from a forming simulation to get accurate forces acting on the die during the topology optimization of the tool structure was explored in [18]. A new load mapping method was proposed in order to seed up the optimization iterations. This method also considers the deflections of the die structure.

The importance to accurately model friction in SMF has been acknowledged by many. An advanced model of the friction behavior in SMF was developed by Hol et al. in [19], [20]. It accounts for the change in surface topography during the forming process and the evolution of friction from adhesion and ploughing in the boundary as well as the hydrodynamic properties of the lubricant itself. It has since been commercialized in the software TriboForm. Another frictional model implemented in Abaqus [21] takes contact pressure, slip-rate and temperature into account. The implementation also makes it possible for die designers to visualize the coefficient of friction (COF) at different stages of the forming process to make better decisions about local surface treatment of the die.

1.3. Platform approaches

There has been research in the past years covering platform approaches, product configurability and standardization in the context of companies with an ETO strategy. Gepp et al. [22] studied the benefits and challenges of using standardization, modularization and platform approaches in ETO companies acting in design and construction of industrial plants. The main challenges are (1) the definitions of relevant key performance indicators for tracking the success and controlling the implementation of the new system. (2) The evaluation of cost and savings from these approaches as the costs and gains usually don't occur at the same organizational locations and the savings are made over longer periods of time, and (3) the lack of methodological support for implementing these approaches.

A platform approach for companies with an ETO strategy, termed design platform (DP), was developed in [23]. It addresses many of the challenges of applying a platform approach to one-of-a-kind products by incorporating many different types of design assets. This is done in order to facilitate the standardization, modularization and platform thinking for processes, synthesis resources, product constructs, assessment resources, solutions and projects, expanding the traditional product platform from [24]. The implementation was done in connection to a PDM-system environment, linking generic product concepts and processes. Raudberget et al. extended the DP by adding support to the early stages of development [25]. By using a Set-based approach to define enhanced function-means tree, different architectural options can be created. These can then be analyzed using clustering of design structure matrices to find suitable modules that have low numbers of external functional relations. These are good candidates for flexible modules that can be changed over time with minimal impact on the rest of the system.

Johnsen et al. [26] proposes a five-step framework for improving modularity in product platforms for ETO companies to improve configurability while keeping the desired flexibility to customize. The framework uses historical data of customizations of a product as well as predictions for the future to identify potential improvement of product modularity.

1.4. Sensors and monitoring

According to Kolhatkar and Pandey [1] "the sheet metal tooling industry has just entered an era of understanding and transitions into the method of bringing in intelligence in the tool". The research reviewed could be categorized into three areas. (1) Measurements of the produced parts in the form of variations in dimensions from spring back, thickness variations from material flow, unwanted wrinkling or tearing and form errors or surface defects. (2) Measurements of in order to determine tool wear, breakage or chipping. (3) Measurements of process conditions during production in the form of forces, strains, friction, temperatures, vibrations, electrical current, acoustics, etc. Some of the possibilities that increased measuring in the SMF process provide is the move from preventive maintenance to predictive maintenance and getting better knowledge and control of capability and efficiency in production.

2. Study of industrial practice

In this study semi-structured interviews with open ended questions were conducted at six Swedish companies (denoted C1-C6) and a total of fourteen employees included. The questions were structured to first describe the process of developing the tools, what design supports are used and motivations for them, how time and cost are distributed in the process for different tasks and then to identify challenges. At each company, the roles of tooling department manager and tool designer were included to get different internal views. The answers were audio recorded and the analysis consisted in categorizing the answers and summarizing them.

C1-C3 are tooling companies with 20-30 employees. C4 and C5 are OEMs and have internal tooling departments and manufacturing. The sites involved in this study have approximately 300 employees. C6 acts as a sub-supplier specialized in manufacturing sheet metal parts with an internal tooling and maintenance department and approximately 200 employees. The manufacturing of the tools, it is mostly done in-house for all the companies. The machinery used consists of machining centers, milling machines, wire EDM machines, grinding machines and hardening furnace. Most of the hardening is done externally.

2.1. Tool development process

There are two clear categories when it comes to the tool development process. The companies that acts as sub-suppliers (C1-C3 and C6) and those that are OEMs with an internal tooling department (C4 and C5). From the interviews, the processes used by the two groups are summarized and shown in Figure 1 and 2 respectively. The main differences between the groups are in the early stages of the process. From step 5 and forward, in the figures the processes are very similar. The differences are (1) that the OEMs tooling designers are involved earlier in the product development process that those at the tooling companies, (2) that the tooling companies have to answer many requests for quotations (RfQ) and (3) that the OEMs in this study have the possibility to conduct the testing in step 12 in production presses while the sub-suppliers conduct their testing in test-presses in-house.

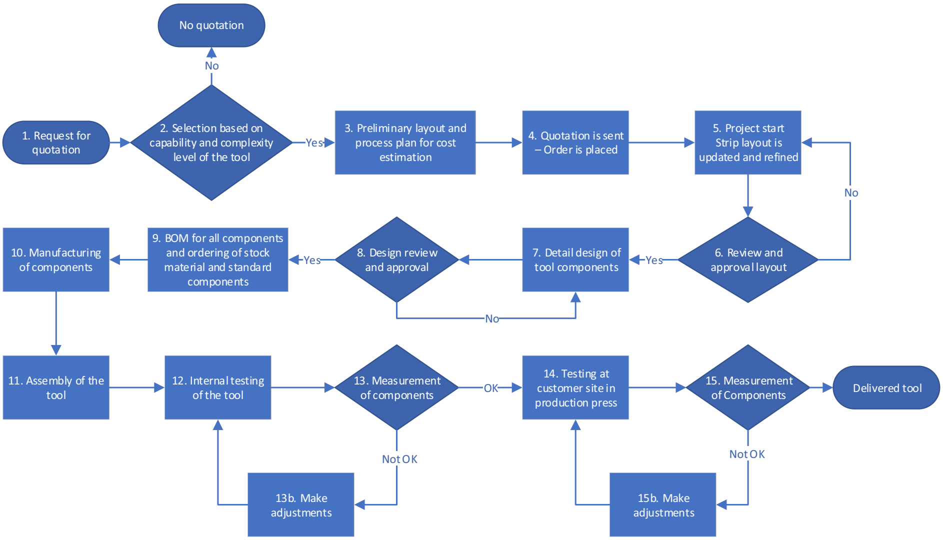

Figure 1. General development process for C1, C2, C3 and C6 (sud-suppliers).

The process in Figure 1 is representative for the sub-supplier companies but some companies differ slightly in some of the steps.

C1: has a structured project management model. A project startup meeting is held in step 5 to discuss timeframe, resources and lessons learnt from similar projects with representatives from design, manufacturing and sales. The internal testing in step 12 is made in a press capable of running at production speed to evaluate the influences of that on the quality of the parts manufactured.

C6: As a manufacturing company they buy many of their tools from tooling companies. When they receive a RfQ for manufacturing of a component they, in turn, send multiple RfQs to different tooling companies. But when they develop a tool in-house, the process in Figure 1 is representative.

For C4 and C5 and the OEM category, Figure 2 describes the general process. As they are involved earlier in the product development process, they can gain more knowledge from discussions with the product designers and creating prototypes. There are some slight differences in some steps.

C4: has multiple checkpoints in step 7 with designers and project leader.

C5: differs from the process in that the tooling department is not as involved in prototyping as no prototype tools are developed. That means they have less emphasis on step 3.

2.2. Time and cost distribution

The data collected for time and cost distribution in tooling projects are presented in total for all companies as the min-max range and averages in parentheses in Table 1 and Table 2. The time spent in a typical tooling project from the point of received order or locked design is usually logged at the companies in the following categories: early cost estimation, design, manufacturing, assembly and testing.

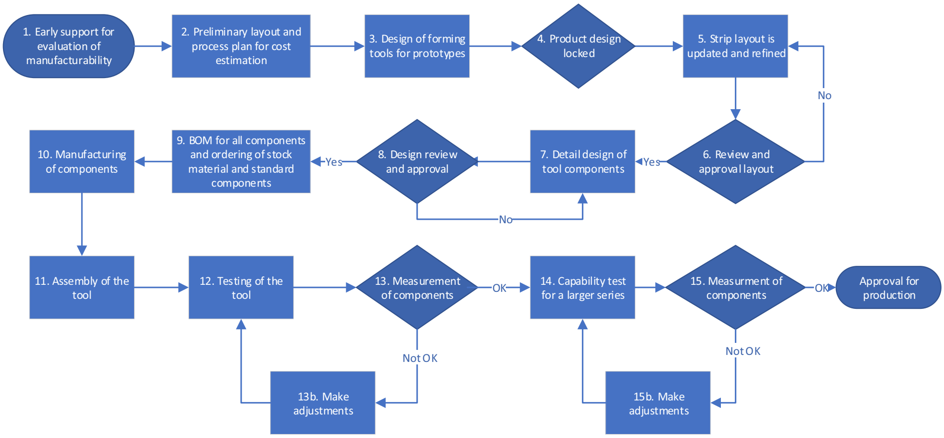

Figure 2. General development process for C4 and C5 (OEMs).

The time for making early cost estimations in step 3 for sub-suppliers and step 2 for OEMs (including estimations for lead time, scrap rate, tool size and technical solutions) is not included in the total time of a project as it is made before the project start. It ranges from 4-8h depending on the complexity of the component and if similar tools have been made in the past. For C1-C3 the hit rate for the quotations they send out can be as low as 2-5% when they work with manufacturing companies where there is a quotation chain. When working with companies who manufacture their own products the hit rate can be 15-20%. For C4 and C5 the early involvement has the effect that cost estimations must be updated following design changes of the products.

Table 1. Time distribution in % of total time spent for categoies of activities in a stamping tool project.

	Design	Manufacturing	Assembly/Testing
Average	16%	58%	17%
Min-max	7-21%	53-76%	8-26%

Time spent on design and manufacturing depends on the size of the tool and the complexity of the sheet metal component and number of components in the tool. The number of test loops in a project can range from 1-6 and take from 2-6h each and involves multiple persons and mostly results in design changes.

The cost distribution in a tool project is broken down at the companies in the following categories: bought material (stock material and standard components), design, and manufacturing (including assembly) and is shown in Table 2.

Table 2. Cost distribution in % of total cost for categoies in a stamping tool project.

	Design	Material	Manufacturing
Average	16%	30%	57%
Min-max	10-20%	25-40%	45-65%

2.3. Supports used

The design supports used by the companies can be categorized in the following categories: CAD (with unfolding functionality), Advanced unfolding, Forming simulation, Design automation, PDM, Quality Checklists, Project management. This is shown in Table 3. Only 2 of 6 companies use forming simulations on a regular basis. Two reasons for that according to the companies are (1) that it is not needed for their type of products or (2) that they do not have the know-how to operate the software. None of the companies use any type of design automation. The reason given for this is either that the task is done fast enough manually or that the software support restricts the way of working too much. None of the companies use any type of PDM-system for their SMF-tools. The reason for this was unanimous and was said to be that common PDM-systems are used for file permission and references and revision handling and that is not needed for them. Checklists and project management tools are sparsely, but the companies not using it, all had the ambition to start using it.

Table 3. Design supports used by the companies.

Support type	C1	C2	C3	C4	C5	C6
CAD	Yes	Yes	Yes	Yes	Yes	Yes
Advanced unfolding	Yes	Yes	Yes	Yes	Yes	Yes
Forming simulation	Yes	No	No	Yes	No	No
Design automation	No	No	No	No	No	No
PDM	No	No	No	No	No	No
Checklists	Yes	No	No	Yes	No	Yes
Project management	Yes	No	No	No	No	Yes

3. Analysis and identification of challenges

From the discussions with the companies the challenges and future research suggestions described in the following sections were identified.

When analyzing the tool development process for the sub-suppliers, described earlier, one of the first steps is to answer a RfQ. To do that, a lot of the planning and major decisions for the tool design must be made at that point. This becomes a problem when the hit rates for orders are low. Then less time can be put into these tasks. The consequences are that the accuracy of the estimations decreases and that the risk of errors increases. This results in either over or under estimation of costs and in both cases the sub-supplier is affected negatively economically. It is noteworthy that few supports to automate and simulate parts of that process (as described in chapter 1) are used by the companies in this study. The systematic reuse of CAD-models, documentation and knowledge from previous projects is also low. The lack of PDM systems makes the information about previous projects only available in the minds of the designers involved. The challenge is to structure the knowledge and methods used in way so that the designers are aided by it in their work, and not restricted (as stated in chapter 2.3). Research analyzing the gap between the methods and technology that exist and what is used in practice and what is needed to bridge the gap is needed. The concepts of platforms have also been researched on a general level for ETO companies, but more research, specific to this industry is needed. For example, how supporting systems and design aids needs to be designed and structured to be adopted and to provide the right information, in the right format, at the right time to aid the designer.

The late stages in the tool development process involves testing of the tool. Drawing the right conclusions and making the correct adjustments from the test results is a critical step. C1 expressed that “an extra test loop can cost the entire profit margin of a project". The use of simulations can make this easier. Another challenge identified and expressed by the companies is that feedback from the testing should be used, not only for making changes to the current tool but also systematically formalizing and storing the knowledge to be used in coming tooling projects. Finding appropriate methods and frameworks for how to enable this would have positive impact.

The OEMs in the study expressed that there are few clear economic incentives, that they currently track, to allow them to prioritize higher quality and more reliable tools for a slightly higher initial cost. Production volumes are often increased from the initial estimations made in product development which might require higher quality material or different technical solutions in the tool. Increasing the knowledge about the SMF-process by monitoring and measuring process parameters has potential to open new opportunities in production and in tool design. Four of the companies have investigated if the use of sensors could be of interest and found that monitoring factors that are connected to accidents, e.g. press force, heat generation and power consumption in the press, have good potential to increase knowledge about the tool.
From the review of the literature of SMF simulations the research done in this area is mostly focused on getting better predictability of the final shape of the components in terms of draw-in and springback to compensate tool dies. Simulation of process robustness for SMF is a research area with a low degree of exploration. It is shown that tribological factors are important for proper predictions [19], [20]. However, C6 expressed that variations in thickness of the coil feeding into the press can be larger that the tolerances for the manufactured component and is not considered with current methods. Models considering these variations could be used to, more accurately, predict the quality of the components.

4. Conclusions

In this study the development processes of sheet metal stamping tools for six companies were mapped, time and cost distribution, and supports used were investigated. From the results and analysis three main challenge areas were identified. To some degree these fit within the category of knowledge capturing and reuse. This points in the direction of efforts needed in supporting the formalization and reuse of information and knowledge from previous tool projects and production, especially during the critical steps of tool process planning and creating the tool layout. There have been attempts to solving these challenges with different approaches. However, finding a good framework that ties the different aspects together in practice still requires research. Future work will investigate, in further detail, what types and forms of knowledge are reused today in the process and what knowledge is needed and useful for completing different tasks. Also, evaluating the applications of frameworks for knowledge reuse proposed in literature to this industry's challenges.

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VR-Enabled Chatbot System Supporting Transformer Mass-Customization Services

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Abstract. Chatbot is a conversational question answering (Q&A) system capable of natural language communication between a computer system and a person. The use of chatbots for 24-hour customer service provides quick responses that solve problems online. This approach is quickly becoming a convenient way for companies to enhance their customer services without location or knowledgeable staff limitations. This research proposes a system framework and develops a prototype virtual reality (VR) enabled transformer mass-customization consultation chatbot. The chatbot technique is a retrieval-based intelligent system. First, thousands of transformer specific frequently asked questions (FAQs) are collected as a Q&A dataset for technical supports retrieval. More than 1.2 million engineering Wikipedia pages and engineering technical papers are used to train a word embedding model used for natural language processing and question-answer retrieval. The chatbot is integrated into a virtual reality (VR) immersive user interface (UI) environment enabling users to make transformer design changes while querying the system about specifications and standards while interacting with 3D models from the company's knowledge base archive. The system provides two unique UIs for personal computer (PC) and a helmet-based immersive interface. The system supports real-time consultation of mass-customized transformers and their bills of materials (BOM) for design review, analysis and cost estimation.

Keywords. Intelligent chatbot, virtual reality, smart manufacturing, electric transformers

Introduction

Intelligent chatbots have been developed using artificial intelligence and natural language processing and thousands of chatbots are actively used globally [1]. Virtual reality is essential for engineering support. Using VR applications, a chatbot can be integrated into an immersive environment to enhance interactions between chatbot knowledge systems and users. At present, chatbots are used for online services in e-commerce and service industries. For engineering or manufacturing firms, chatbot development faces challenges due to the technology-specific knowledge required to build sophisticated engineering linguistic consultation. For example, power transformers are engineering assets that are critical machineries used in electric power distribution. Because of the high customization required in power transformer design and manufacturing, a smart consultation agent (or chatbot) that can communicate and answer technical questions effectively must understand the company's knowledge base as well as the customers' requirements. People often spend a lot of time searching for answers to engineering-related issues because of the lack of specific domain knowledge or the mismanagement of creating knowledge-based systems to store the intangible assets of the firm. There is a need for an interface where the manufacturers can interact with their customers, answer technical FAQs in real time, and re-use elements of design and engineering that are proprietary to the firm. Therefore, this research aims to integrate the consultation chatbot with a VR environment for transformer mass-customization Q&As which automatically and accurately provide knowledgeable technical support to customers at a delivery rate that surpasses existing methods.

1. Literature review

In this section, the literature of related methodologies in VR and chatbot technologies are reviewed. Chatbot, also known as talkbot or service agent, is a software that creates user friendly conversations with users via text or voice. Chatbots can deliver real-time service to customers and intelligently simulate the communication between the system and user [2]. Based on different design techniques, chatbots are classified rule-based chatbots and artificial Intelligence (AI)-based chatbots. AI-based chatbots are classified as retrieval-based chatbots and generative-based chatbots [3]. Rule-based chatbots are constructed using pre-set scripted dialogs. The chatbot will provide answers according to the logic of the known domain. The techniques used in ruled-based chatbot are less intelligent and lack interaction. The benefit is that the construction cost is low and acceptable results can be realized if the script is written sufficiently and creatively [1]. Retrieval-based methods use natural language processing techniques to efficiently select proper responses from existing conversational data and generates responses using natural language generation models trained by conversation data [4].

As an intangible asset, patent documents are widely used in business. Through patent analysis, there are many methods to structure and understand the specific knowledge domain using algorithms. Hong, et al. [5] present an advanced approach to generate a patent map which is called the Technology Function Product Matrix (TFPM). The research uses the generated matrix to present the analysis of dialog system technology in chatbots and provides the hotspot distributions of key technologies, functional improvements, and novel applications. Table 1 shows five patent developments related to chatbot dialog systems. Chatbot related patents tend to focus on intent detection and domain identification. Intent detection is a technology which uses text mining algorithms and detection rules to detect user intention. The results show embedded device and natural language understanding are the current technology developments. NL understanding is a method where systems assume what a speaker actually means. Further product application applies dialogue function analysis to an embedded system. From the discussion of identified technology trends, the chatbot related technologies are shown in Table 1.

Table 1. Top 5 patent hotspots of dialog system in chatbots.

Technology sub-system/ function or product	Patent count
Intent detection (T22)/ Embedded device (P3)	141
Domain identification (T21)/ Embedded device (P3)	122
Intent detection (T22)/ NL understanding (F1)	114
Content planning (T41)/ Embedded device (P3)	113
Domain identification (T21)/ NL understanding (F1)	109

Virtual reality (VR) technology enables users to have the feeling of being present in the environment and creates a virtual interaction with the human interacting with the system [5]. For manufacturing industries, virtual reality has been applied for many years and was first reported to as a simulation tool in the 1960s [6]. The advances of virtual reality (VR) or augmented reality (AR) technologies have provided different engineering applications, such as manufacturing planning, process simulation, product design and testing, modelling, and employee training [7]. For example, Gonzalez-Badillo et al. [8] present a virtual reality haptic enabled platform. The platform provides an environment to design, plan, and evaluate virtual manufacturing assemblies of components while allowing engineers to manipulate and interact with virtual components in real-time. Peng et al. [9] present a VR system for interactive modular fixture configuration design and apply a multi dimension modular fixture assembly model to enhance visualization and management. The proposed 3D manipulation approach improves intuitive interaction and more accurately positions components in the virtual environment which is then transferred to actual manufacturing.

2. Methodology

In this section, the method and framework of three sub-systems are introduced: chatbot (question answering system), cost estimation system, and the virtual reality environment. In the first sub-system, the FAQ data collection, data preprocessing process, and information retrieval for the question answering system are proposed. The second part explains the methods of building a knowledge base to store key information of power transformers and cost estimations based on previous Bills of Material (BOM). For the section describing the virtual reality engine, modeling software building 3D models, the development and execution environment in Unity, scene design, objects control, and applications on different platforms are described. The framework of the proposed consultation system is shown in Figure 1, and details of the system are discussed in the following sections.

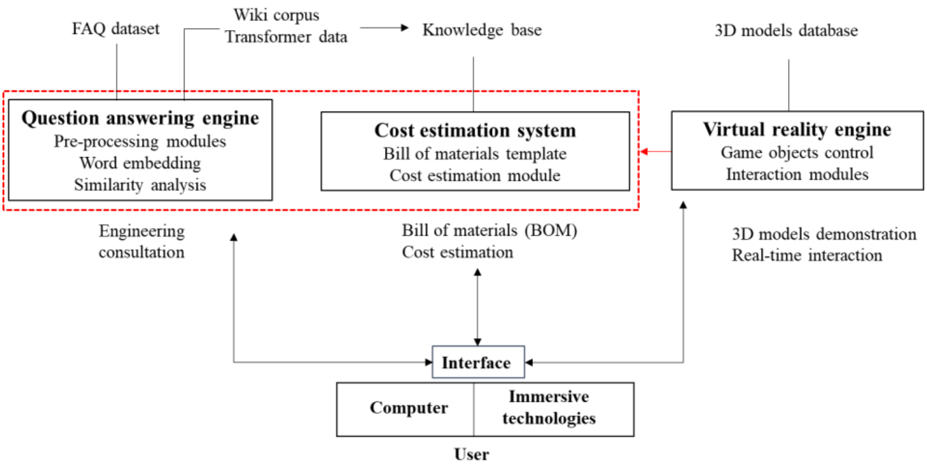

Figure 1. Framework of VR enabled chatbot for a power transformer manufacturer.

2.1. Chatbot (Q&A system)

The computerized question and answering system provide users with a way to communicate in natural language receive answers instead of web pages. The design technique of the chatbot in this research is to use a retrieval-based similarity calculation in response to a selection from the FAQ (Frequently Asked Questions) conversation data set.

The retrieval-based question answering system allows users to ask questions in natural language and retrieve answers from a large number of heterogeneous materials accurately and quickly. The chatbot eliminates the process of reorganizing the answers and improves the efficiency of the systems accuracy of answers. The FAQ collection benefits the similarity between the user question and the questions in the data set with returning the best result to the user. The process of selecting an answer in the question answering system in this research can be divided into the following steps and the flowchart of the system is shown in Figure 2.

1. Pre-process questions to remove non-informative words and save computing time.
2. Derive word vectors and calculate the similarity between user's question and each question in FAQ dataset. The answer corresponding to the question with the highest similarity is returned to user.

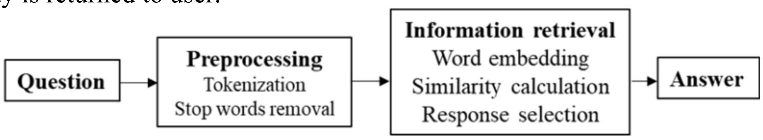

Figure 2. Flowchart of question answering.

The tool used to train a word embedding model is called Word2Vec [10]. Word2vec is a prediction-based model that predicts adjacent words. The word vector is part of the model parameters, and the best word vector model is learned during model training. After deriving the vectors of every word in a question sentence, the similarity calculation between the user's question and questions in dataset is conducted. The cosine angle is used to calculate the similarity between the vectors, which is called cosine similarity.

The value of each cosine similarity is between 0 and 1. The larger the value, the higher the similarity of the two words. Cosine similarity works in vector spaces of any dimension, and is most commonly used in high-dimensional positive spaces, i.e. information retrieval. The formula of cosine similarity is:

$$\text{Similarity} = \cos\theta = \frac{\sum_{i=1}^{n} Ai*Bi}{\sqrt{\sum_{i=1}^{n} Ai^2}\sqrt{\sum_{i=1}^{n} Bi^2}} \quad (1)$$

Ai and Bi are components of vector A and vector B respectively.

2.2. Cost estimation system

Power transformers are the primary equipment of power plants and substations and are highly customized to satisfy customer needs. It is necessary that manufacturers and customers have honest communications when negotiating prices. By introducing the cost estimation sub-system, customers have a preliminary understanding of the price of the product. A Request for Quotation (RFQ) in the power transformer industry is a document used to request for bids from qualified manufactures of transformers. The RFQ document specifies the requirements of the transformer to be purchased. The requirements could be details such as how it will be constructed and designed, desired components or the standards to be followed. The first task to construct a cost estimation system is to build a knowledge base (KB). The knowledge base contains the estimated cost of all possible key materials and components of a transformer. These costs are compared to the identified key components with the KB, the BOM tables, and then the estimated costs are tabulated.

The Bill of Materials (BOM) generation enables the customer to acquire a tentative cost of the required transformer product when receiving a summary of RFQ document. The summary report contains specifications for the requested transformer such as capacity, voltage, and phase. These quotes are critical factors that determine product cost that enable manufacturers and customers flexibility in bargaining. Figure 3 shows the process of BOM generation. The information in RFQ summary will be compared with the knowledge base (KB) to identify the key components and their required raw materials. All the extracted components will be decomposed to a list of required raw materials. Based on the material information, the estimated tentative cost of a transformer will be calculated. Once all the components in RFQ summary file have been compared, the list of components, materials, and total estimated cost will be used to generate a BOM and send back to the user in a virtual environment.

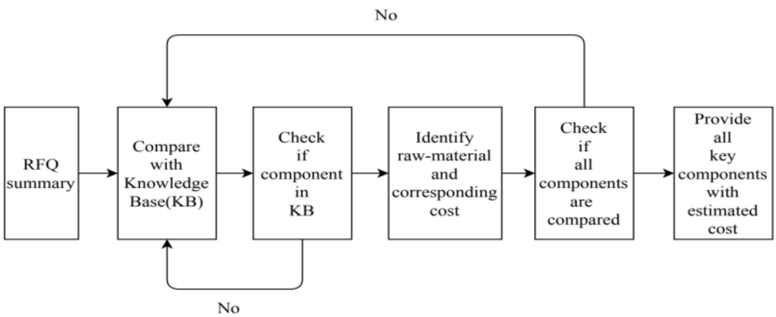

Figure 3. Flowchart of BOM generation.

2.3. Virtual reality environment

Using the virtual reality (VR) environment, the consultation system provides a three-dimensional (3D) transformer model to customer and also enables users to interact with the model. The system can operate on two different platforms. User can simply see the model and interact with the 3D objects using the mouse and keyboard of a computer. The second platform enables immersive technologies where the user can wear an HTC VIVE helmet and controller. Users can experience an immersive environment to see the model and have a clearer and more intuitive understanding of the product. The following sections introduce the modeling software used in this research and the development of Unity 3D game engine applications.

In this research, SolidWorks, the first Windows-based 3D CAD modeling software, is used in engineering design and provides a powerful platform for the design of components, especially the assembly of large components which are hard to visualize. SolidWorks simplifies assembly design and provides the same visualization as real-world, design-and-obtain, and allows users view, rotate, and even enter the interior of the equipment. Unity 3D is used to construct the user interaction environment.

Unity is a cross-platform game engine which enables users to create games, simulations and interactive experiences in both 2D and 3D, and the engine offers a primary scripting API in C#, for both the Unity editor in the form of plugins, and games themselves, as well as drag and drop functionality. The development environment of Unity can be divided into several parts: scene design interface, scene object structure, object structure, object list, object attribute, execution interface. When designing the user interface of the Unity program in this research, it is divided into three parts: the chatbot (dialogue window), model interaction area and the functions list. Chatbot (Dialogue window): Users can interact with the chatbot system within a dialogue window to conduct an engineering consultation in this virtual environment via a keyboard or microphone. Model interaction area: In this area, users can interact with 3D models in real time, for example, users can click on the key components (i.e. conservator, bushing, cooling system) to view relevant specification information and use the specified buttons or commands to disassemble the model to seeing the internal core structure. Functions list: The functions list enables users customize the components or specifications of models. Figure 4 summarizes the structure of functions in the immersive environment. The introductions of the interface and achieved functions are described in the Section 3.

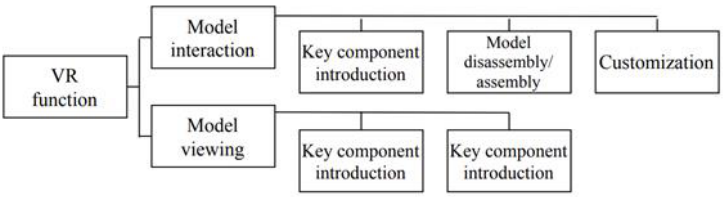

Figure 4. Structure of VR functions.

2.4 Systems integration

The previous sections discuss the methods and processes for constructing the three sub-systems. This section discusses how to integrate question answering systems (chatbot) and cost estimation systems into a virtual reality environment. The first subsystem includes a preprocessing module, a word embedding model, and a similarity calculation module. The research uses Python to implement tasks of natural language processing. Python provides a rich Natural Language Toolkit library to help with pre-questioning, word vector model training. We utilize the trained model and load the model with the package in .NET Framework so that the retrieval-based system can be accessed in the virtual reality development software Unity. Since the chatbot is integrated into a virtual reality environment, the chatbot interface also includes the function of displaying the relevant components or specification information of power transformers. The related information of the key components will be displayed in the dialogue window when users click on the key components. For example, if users want to know what the cooling system is, they can simply move the mouser on the equipment and the specifications and model of the cooling system will be immediately displayed in dialogue window. In this way, users can conduct engineering consultation within the chatbot interface and retrieve information.

In the second sub-system, due to the large number of equipment and materials in power transformers, a structured database is needed to store information in a knowledge base. The information of the knowledge base uses the MySQL database server. The information includes raw materials, specifications, unit cost of key components stored in the MySQL server that can be passed back to the Unity environment of the chatbot to generate a bill of materials (BOM) table and presents tentative cost using a .Net Framework package.

3. Implementation

The system for this provides real-time engineering consultation, automatically generated bill of materials (BOM) for cost estimation when receiving an RFQ summary file, and provides user an immersive environment to interact with 3D models. This section discusses the implementation of the system including the introduction of functions and interface design of the question answering system (chatbot). Included in the discussion is an overview of the virtual reality environment, output of cost estimations, scene designs, transformer models construction and illustrations of user interaction in an immersive environment.

3.1. Chatbot development

The system provides an interface in which users can easily ask questions (in plain English), and receive a concise and insightful answer in real-time. The chatbot also integrates speech recognition, allowing users to communicate directly with the system through voice input. The question-answer dataset used in this system comes from the public FAQs on the webpages of different transformer suppliers. The answering capability of consultation chatbot depends on the completeness and correctness of the FAQ database. Therefore, the collection of the FAQ database is a crucial factor. The questions include many types, including transformer knowledge, and customer support consultation. Table 2 provides examples of the FAQ database.

Table 2. The sample FAQs for chatbot retrievals.

Question		Answer
Transformer	What is material of transformer core ?	A transformer core is made from many sheets if special steel to reduce losses and. …
International Standard	What is the international standard we should choose?	In accordance with the IEEE standard design will be the most economical …
Customer Service	How long does installation take?	General 6-8 weeks
Engineering Knowledge	What is induced electricity?	Electricity generated by relative motion of a magnetic field and an electric charge.

Retrieval-based chatbots rely on a complete and systematic database construction. This research enters 100 questions into the chatbot dataset to evaluate the accuracy rate of the question answering system. The questions are collected from a website called Quora. All the questions and answers in Quora are created, edited, and organized by the people who use it. The source of the database used in this research is the FAQs from engineering manufacturers, the testing questions can be used to test whether the chatbot system can answer the public's questions about the transformer and further improve or update the database. From the results of testing, there are 14 wrong answers out of 100 questions tested, with an accuracy rate of 86%.

3.2. Output of cost estimation system

This section introduces the result of the second sub-system of the research. Based on previously mentioned processes of the cost estimation system, the user is required to upload a file of the RFQ summary into the proposed system. The cost estimation system will compare each component of the RFQ summary with the KB and check if all of the components satisfy an output which includes all key components within estimated costs. The partial output of the cost estimation system is shown in Figure 5. The system extracts the key components from the RFQ summary which the user provides, such as copper wire, type of insulating oil, number of fans, and the type of winding.

This information is critical to the design of the transformer and determines the cost. Furthermore, the supplier of transformers has the tentative costs estimation report which helps to decrease the time of processing an order. This enables manufacturers and customers to be more efficient in establishing a reasonable price.

No.	Name	Quantity	Unit	Spec	Cost
1	Copper Wire	1067.25	KG	325mm	218,788.00
2	Tape	9.00	ROLL	P-G 50W	57,162.00
3	Insulating Tube	1.00	SET	-	131,892.00
4	On Load Tap Changer	1.00	SET	-	2,614,742.00
5	Latch R	1.00	PIECE	SIEMENS	9,143.00
6	Electric Wire	5000.00	FOOT	SIS/XHHW-2	55,483.00
7	Insulating Oil	34064.00	L	NAD	1,076,868.00
8	Fan	6.00	PIECE	-	155,102.00
9	Oil Level Gauge	1.00	SET	QUALITROL	17,250.00
10	Silicon Steel Plate	14719.00	KG	F27D090	1,349,168.00
..	..	..	..	..	..
..	..	..	..	..	..
				Total Cost：	13,842,114.00

Figure 5. The example output of BOM cost estimation module.

3.3. VR-enabled transformer mass-customization demonstration

This section introduces the implementation of the QA system and the cost estimation system within the immersive environment. In addition to the abilities of question answering and cost estimation, the proposed system can provide an immersive environment that the user interacts with. Users can interact with the 3D models using a keyboard or mouse without the virtual reality hardware. The other platform enables users to interact with the consultation system using a helmet and controller in the immersive environment. The following section focuses on introducing scenes design and objects control in the constructed immersive environment.

According to the customer's requirements, the environment of presenting a power transformer model can be divide into two situations: indoor and outdoor. As shown in Figure 6 (both outdoor and indoor scenes), the outdoor environment simulates a transformer built in a desert. In the real-world issues such are "how to outlay the electric wire" and "how to determine the precise position of the transformer" must be considered during design. The VR chatbot can help the manufacturer and customer increase the efficiency of the design process. Another scene simulates a large transformer set in a building, which has space limitations including the scale, vibration, and noise of the transformer. Consequently, the VR system can provide an environment which helps the user or manufacturer clearly understand the transformer installation.

Figure 6. The outdoor and indoor transformer scenes.

In addition to the presentation of the model and the environment, the VR system can interact with the user in real time. Figures 7 presents the animation of transformer disassembly. Users can control the events by saying a specific word. For example, the user can say: "disassemble" to the system. Within two seconds, when the speech recognition system receives this command, it will generate the model disassembly animation. By disassembling transformer, the user can better understand the details of components and structure. This also helps the manufacturer to provide a better visual presentation when introducing products to customers. Another function of the immersive environment is transformer hyalinization. Users can control the events by using the controller or mouse to trigger the button. The transparency of the transformer will gradually increase when users click the button. Using transformer hyalinization, users can obviously see the detail of coil and inner structure. As discussed before, power transformers are highly customized products. The VR system provides the function of replacing transformer components or selecting other transformer models. As shown in Figure 7, users can change components or models by using the controller or the mouse to interact with system. By introducing these functions, users can select the components or models which they want and further acquire the related information, which can increase efficiency of the communication.

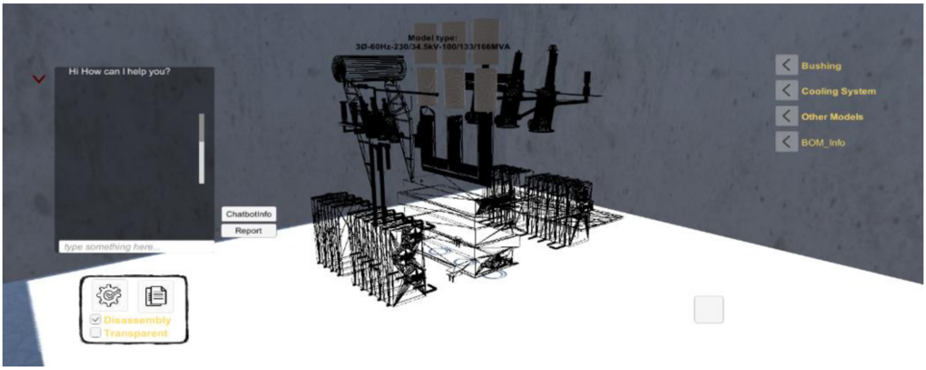

Figure 7. The transformer disassembly for detailed design review.

4. Conclusion

This research proposes a system framework of a chatbot that integrates Q&A system into a VR environment. In addition to providing engineering consultation, the system also combines the advantages of VR to provide a user 3D model interface which helps improve understanding of complex transformer designs. The contribution of this research is to propose a VR enabled engineering consultation chatbot that users can interact with simultaneously with an immersive environment. This allows for users to ask technical questions, obtaining tentative costs, while interacting with 3D models for vivid design reviews for mass customization of complex products.

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A Hybrid Heuristic Optimization Approach for Green Flatcar Transportation Scheduling in Shipbuilding

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Abstract. To increase efficiency and decrease energy in fierce competition, higher standard of transportation scheduling mode for shipbuilding is necessary and urgent. By analyzing the "one-vehicle and one-cargo" transportation scheduling problem in shipbuilding, this paper proposes a bi-objective mathematical model and design a Multi-Objective Tabu Search algorithm(MOTS) to minimize total carbon emission and transportation time cost. Further, to improve the computation performance of the solution method, we combined NSGA-II and MOTS to design a hybrid heuristic algorithm. Computational experiments compare three optimizing approaches and reveal that MOTS and NSGAII-MOTS have certain advantages in terms of solution effect and convergence speed in large-scale instances. The case shows the proposed optimization approach can reduce carbon emissions by 61.22% for daily transportation.

Keywords. Transportation scheduling, green transportation, multi-objective optimization, hybrid heuristic optimization

Introduction

Shipbuilding adopts a typical pulling production method. "Segments" are basic operating units for ship construction process, which need to pre-process, assemble, outfit in different yards before general assembly and loading. Due to the heavy load, segment logistics is important for organizing the ship construction process flows. The transportation of ship blocks mainly depends on heavy flatcars, which are scarce resources in shipyards. The daily fuel consumption and carbon emission of flatcars are high. A large-scale shipyard in Shanghai produces 36 ships per year, with an average of 200 segments per ship, the basic operation of the flatcar is 160 times per day. Based on the average workload of 2km per time, about 2172kg CO_2 emission per day will be generated by flatcar transportation.

The value proposition of this paper in transdisciplinary systems engineering is embodied in energy, logistic, and computer science domains to achieve successful diffusion(10) . In particular, it is demonstrated in terms of time for traditional metrics and quantifying transport energy consumption, and a bi-objective mathematical model is

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proposed to further explore a high efficiency and low energy consumption transportation scheduling mode.

Figure 1. Transport ship block by a flatcar.

1. Previous studies and techniques

Flatcar transportation scheduling problem in shipyards is different from traditional VRP. Nowadays, the research on the ship block transportation scheduling is systematizing at home and abroad. Meanwhile, the optimization algorithm are becoming mature, such as GA(10), greedy algorithm(10), meta-heuristic algorithm(10), ACO(10), etc.

Transportation is one of the main sources of greenhouse gas emissions, and green vehicle transportation problem has become a research hotspot. Table 1 summarizes and compares GVRP-related research in terms of types and solution methods. With the intensification of environmental pollution and scarcity of resources, green transportation has become an inevitable development trend of ship block transportation scheduling. Flatcars generate a large amount of carbon emissions. However, there are few researches on the green flatcar transportation scheduling in shipyards at home and abroad, and only a few scholars in China have studied green scheduling problem in container terminals.

Table 1. The comparison of GVRP-related research literature.

Autor	Problem types		Vehicle speed		Solution method
	Scheduling	Route Planning	Yes	No	
Li et al. [7] (2013)	√			√	Fuzzy multi-objective optimization algorithm
Guo Zhaoxia et al.[8] (2016)	√			√	Novel memetic algorithm
Salehi et al.[9](2017)	√		√		Novel constructive heuristic
Zhang et al. [10](2018)	√	√		√	ACO
Wang Yong et al. [11] (2019)	√	√	√		Multi-objective particle swarm optimization

2. Problem statement

2.1. Problem description

The problem of flatcars scheduling in shipyard based on OVOC mode can be described as follows: there are n transportation tasks and m flatcars. Each transportation task includes: task number, segment number, segment weight, start location, destination, and time window (when the task can be started). Each heavy flatcar includes: flatcar number, flatcar ID, load-bearing capacity. Each transport task must be performed within a time window by a heavy flatcar that meets its segmented weight requirements. The following Figure 2 is the distribution map of road junctions, the location of the yards, and parking location of a shipyard in Shanghai, China.

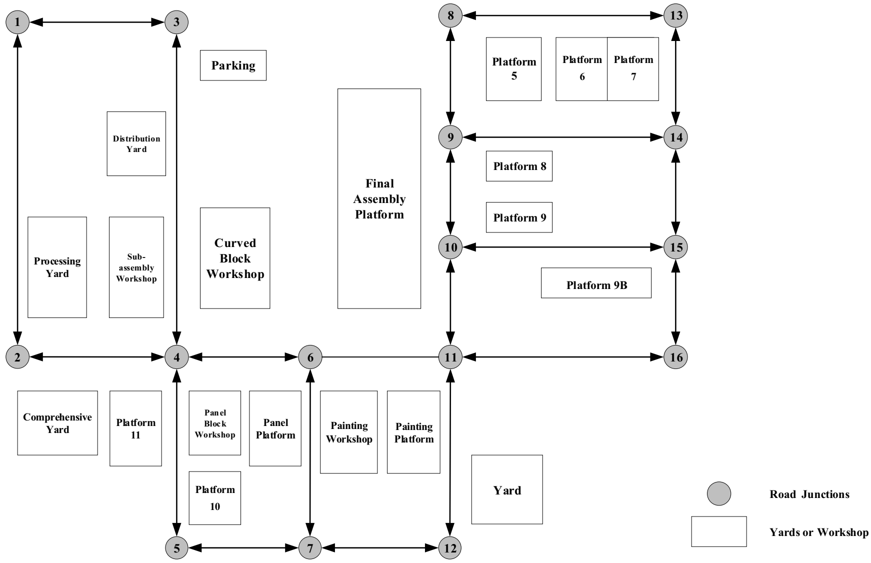

Figure 2. Distribution map of intersections and yards.

The basic assumptions of the problem are as follows:

1. All segments in the task table meet the load-bearing requirements of flatcars, and the order of tasks can be changed.
2. The flatcar can't be interrupted during the mission.
3. A single flatcar cannot transport multiple segments at the same time.
4. Without considering the road factors, such as the interference.
5. Set the loading and unloading time of the flatcar to a fixed value and add it to the task execution time.
6. The target yard must be able to accommodate the transported mission segments.

Based on the above assumptions, the problems to be solved are as follows:

1. Transport task sequence on each flatcar.
2. The optimal route for each flatcar.
3. The actual start time of each task.

2.2. Mathematical model

The factors that evaluate the quality of the flatcar driving route are: 1) the length of the route; 2) the number of turns during load driving. We use the depth-first search algorithm([6]) to traverse all feasible paths and consider the factors of turning.The definitions of model-related parameters and decision variables are shown in Table 2.

Table 2. The indices, parameters and decision variables.

Notation	Meaning
x_P	Abscissa of intersection p
y_P	Ordinate of intersection p

m_i	Number of turns when task i is performed
T	Task number set T={1,2,…,n}; $i,j \in T$, where $i \neq j$
F	Flatcar number set F={1,2,…,m}; $f \in F$
L	Flatcar speed set L={3,6}, the unit is m/s
$lsp, nlsp$	lsp represents load speed; $nlsp$ represents no-load speed of the flatcars
LT_i	Execution time of the task i
NLT_{ij}	No-load driving time to the starting point of task j after performing task i; where $i = 0$ or $j = 0$ represents that the flatcar departs from or returns to the parking lot
M	Infinite positive number
$[es_i, ls_i]$	The time window of task i; es_i is the time starting point at which the task can start executing; ls_i is the time ending point at which the task must start
$[E, L]$	Time window of the opening and closing of the parking lot
w_i	Segment weight of task i
cw_f	Load-bearing capacity of flatcar f
λ_1	The weight of no-load travel time for all tasks performed by the flatcar
λ_2	The weight of waiting time for the flatcar
efc	Transport efficiency of flatcar, set $efc = 0.8$
β	Specific constants of flatcar, set $\beta = 2.1072$
α	Specific constant of road ($\alpha \in [0.09, 0.2]$), set $\alpha = 0.0981$
f_e	The fuel emissions for diesel fuel, set $f_e = 2.621$
υ	Conversion factor for fuel consumption per Joule energy ($\upsilon = \frac{1}{3.6\times10^6\times8.8}$)
dis_i	Distance between start and end of task i
dis_{ij}	Distance from the end of task i to the start of task j
TC	The time flatcar takes to make a turn, the unit is min / time
Decision Variables	
x_{oif}	0-1 decision variable for flatcar f to perform its first task i
x_{ijf}	0-1 decision variable for task i, j execution order on flatcar f
x_{iof}	0-1 decision variable for flatcar f to perform its final task i
y_{if}	0-1 decision variable for whether platform f performs task i
s_i	Actual start time of task i

The mathematical model to minimize total non-value-added transportation time and total carbon emission of the flatcars is presented as follows:

$$Min\ f = \lambda_1 \cdot (f_1 + f_2) + \lambda_2 \cdot f_3 \tag{2.1}$$

$$Min\ e = e_1 + e_2 \tag{2.2}$$

$$f_1 = \sum_{f \in F} \sum_{j \in T \setminus i} \sum_{i \in T} x_{ijf} \cdot NLT_{ij} \tag{2.3}$$

$$f_2 = \sum_{f \in F} \sum_{i \in T} x_{oif} \cdot NLT_{oi} + \sum_{f \in F} \sum_{i \in T} x_{iof} \cdot NLT_{io} \tag{2.4}$$

$$f_3 = \sum_{f \in F} \sum_{j \in T \setminus i} \sum_{i \in T} x_{ijf} \cdot (s_j - s_i - LT_i - NLT_{ij}) \tag{2.5}$$

$$e_1 = \sum_{f \in F} \sum_{j \in T \setminus i} \sum_{i \in T} \frac{f_e}{efc} \times x_{ijf} \times (\beta \times nlsp^2 + \alpha \times w_f) \times \upsilon \times dis_{ij} \tag{2.6}$$

$$e_2 = \sum_{f \in F} \sum_{i \in T} \frac{f_e}{efc} \times y_{if} \times [\beta \times lsp^2 + \alpha \times (w_f + w_i)] \times \upsilon \times dis_i \tag{2.7}$$

$$\sum_{i \in T} x_{oif} = 1, \forall f \in F \tag{2.8}$$

$$\sum_{i \in T} x_{iof} = 1, \forall f \in F \tag{2.9}$$

$$s_i + LT_i + x_{ijf} \cdot NLT_{ij} - s_j \leq (1 - x_{ijf}) \cdot M, \forall i, j \in T, i \neq j, f \in F \tag{2.10}$$

$$es_i \leq s_i \leq ls_i, \forall i \in T \tag{2.11}$$

$$s_i + LT_i + NLT_{io} \leq L, \forall i \in T \tag{2.12}$$

$$E \leq s_i - NLT_{oi}, \forall i \in T \tag{2.13}$$

$$w_i \leq \sum_{f \in F} y_{if} \cdot cw_f, \forall i \in T, f \in F \tag{2.14}$$

$$\sum_{j \in T \setminus i} x_{jif} + x_{oif} = y_{if}, \forall i \in T, f \in F \tag{2.15}$$

$$\sum_{j \in T \setminus i} x_{ijf} + x_{iof} = y_{if}, \forall i \in T, f \in F \tag{2.16}$$

$$x_{ijf} + x_{jif} \leq 1, \forall i, j \in T, i \neq j, f \in F \tag{2.17}$$

$$\sum_{f\in F} y_{if} = 1, \forall i \in T \tag{2.18}$$

Objective functions are presented in (2-1) and (2-2). Objective (2-1) represents the minimizing total non-value-added transportation time of the flatcars and (2-2) represents the total carbon emission of the flatcars. Objective (2-1) contains three parts. It includes the no-load travel time f_1, f_2 and total waiting time f_3.The formula of f_1 is shown in (2-3). It represents the no-load travel time between two adjacent tasks performed by the flatcar. In (2-4), f_2 represents the no-load travel time for the flatcar exiting and returning the parking lot. In (2-5), f_3 represents the waiting time of the flatcar arriving earlier than the time window. Objective (2-2) contains two parts. Carbon emissions of no-load flatcar traveling between two adjacent tasks is show in (2.6). In (2.7), e_2 represents carbon emissions of load driving in tasks.

Constraint (2-8), (2-9) ensure that each flatcar only has one first and final task and (2.18) ensures that each task is performed by one flatcar. Constraint on the start time between the adjacent tasks is done by (2-10). Constraint (2-11) represents the task time window constraint. Constraint (2-12), (2-13) limit the time window of the parking lot. Constraint (2-14) ensures the task segment weight and flatcar load-bearing capacity. Constraint (2-15), (2-16) put limitation on the number of times a task appears in each flatcar. Constraint (2-17) indicates that the adjacent tasks cannot be repeatedly executed.

3. NSGAII-MOTS Hybrid Optimizing Approach

The MILP model established in this paper is based on the research of Li Baihe et al([6]). The increasing green goal of carbon emission determines that we need to solve the multi-objective optimization problem. This paper designs a multi-objective tabu search (MOTS) algorithm, and proposes a hybrid optimization algorithm combining NSGA-II and MOTS. In NSGAII-MOTS algorithm, NSGA-II is used to obtain a better solution set, and the optimal solution is input into MOTS algorithm to continue solving.

The chromosome is designed as two one-dimensional arrays based on positive integers, which respectively represent the task sequence and the flatcar sequence. During decoding, each task is assigned to corresponding flatcar according to chromosome coding, and the task order on the flatcar means the execution order.

We propose two methods of constructing neighborhood solutions: (1) Local search for task sequence. The neighborhood solution is obtained by exchanging the position of two tasks, which are performed by a randomly selected flatcar. (2) Local search for flatcar sequence. A task is randomly selected, and the flatcar corresponding to it is replaced with a newly generated flatcar that meet the weight requirement. In each iteration, when generating neighborhood solutions, the above two methods are selected according to the fixed ratio.

Task sequence	3	4	6	1	5	2	9	7	10	8
Flatcar sequence	2	3	1	4	1	4	2	3	1	3

Figure 3. Chromosome coding.

In our hybrid optimizing approach, NSGA-II is used to get a high-quality solution, and then MOTS is used to continue the search. The specific steps are shown in Figure 4.

Step1: Input the information of the task, flatcar, and coordinates of yards, workshop, platform and intersection. Initialization parameters: population size ($popsize$), single-point crossover rate (p_c), exchange mutation rate (p_m), elitism preservation rate (p_r), maximum iterations, unimproved times and iteration times.

Step2: Randomly generate the task sequence, once for each task, and the flatcar meeting the weight constraint is generated randomly for each task. The population size is popsize, and these random individuals formed the initial population.

Step4: Calculate non-dominated rank of each individual in the population.

Step5: Calculate crowding distance of each individual in the population.

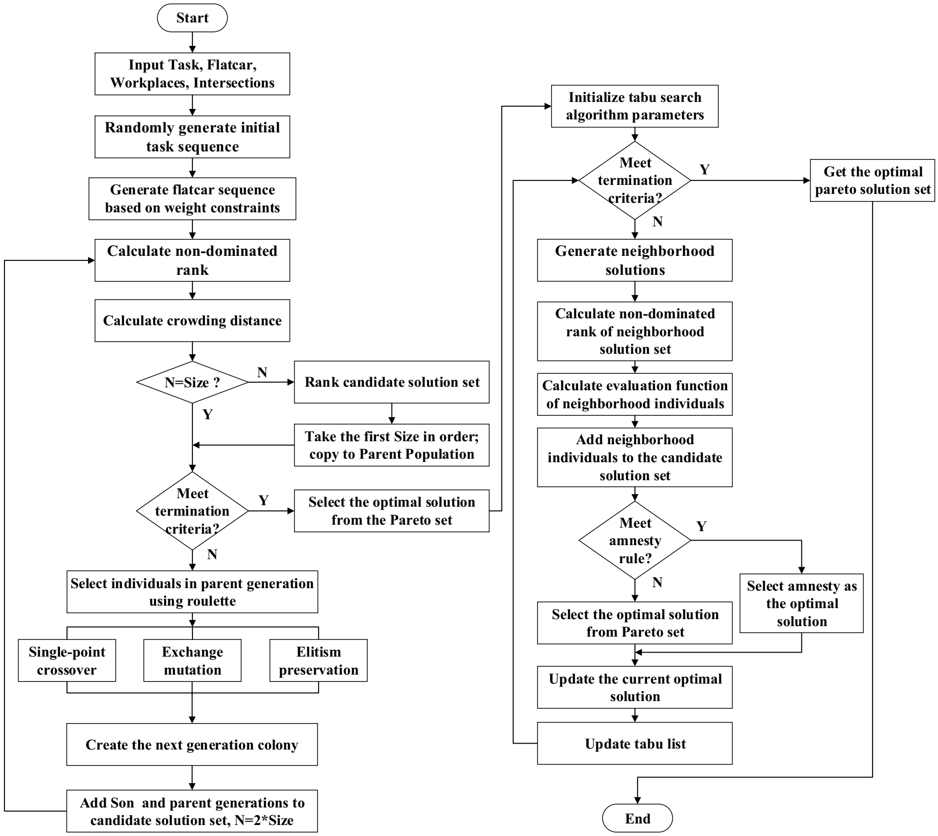

Figure 4. Hybrid optimization algorithm flow.

Step6: If the population number $N = popsize$, proceed to step 7; otherwise, go directly to step 11.

Step7: If the times meet the termination criteria, go directly to step 12. If not, proceed to step 8.

Step8: Use roulette method to select individuals in the parents.

Step9: Use single-point crossover to generate $popsize \cdot p_c$ offspring, and use exchange mutation to generate $popsize \cdot p_m$ offspring, and then use elitism preservation strategy to generate $popsize \cdot p_r$ offspring, where $p_c + p_r + p_m = 1$.

Step10: The offspring and parent are mixed into the candidate population. The iteration time is increased by 1, and go back to step 4.

Step11: The candidate population is sorted in ascending order of non-dominant rank, and descending order of crowding distance. Take the first $popsize$ in order to substitute the parent population.

Step12: Use NSGA-II to find the optimal solution as the initial solution of MOTS algorithm (current iterative solution), and initialize the parameters: neighborhood space n_size, tabu length, maximum iteration times, and iteration times.

Step13: If the times meet the termination criteria, the algorithm solution ends. If not, proceed to step 14.

Step14: Use the current iterative solution to generate n_size neighborhood solutions, and calculate the non-dominated rank and the evaluation function of each individual.

Step15: If the solution meets amnesty rule, update the current optimal solution with amnesty.

Step16: Update the tabu list, if the current solution is feasible, then update the optimal solution; otherwise, do not update. The iteration time is increased by 1 and go back to step13.

4. Numerical experiments and discussions

4.1. Algorithm comparison analysis

This section describes computational results to compare three optimization algorithms which are implemented in Java. The computer running the test is configured with Intel (R) -64 Core (TM) I5-7200U CPU @ 2.50GHz 2.71GHz.

The test datasets are encoded as"$TxFy$", where"x" is the number of tasks, and"y" is the number of flatcars. By setting different combinations of task numbers (T=10,20,30,40,50) and flatcar numbers (F=2,3,4,5,6,7,8), the solving effects of three different algorithms are compared. The main parameter settings of NSGA-II and MOTS are shown in the Table 3. The result is the average value of 5 times for each test.

Table 3. Default parameter settings of the NSGA-II.

Parameters	Values
Population size	100
Maximal generation/iteration	NSGA-II (300), MOTS (300), NSGAII-MOTS (50+300)
Crossover / Mutation rate	0.4/0.4
Retain Elite probability	0.2
Neighborhood space size	500
Tabu length	300

The test results are shown in Table 4, where f represents the total non-value-added transportation time of the flatcars (unit: min), and e represents the total carbon emission of the flatcars (unit: g). The results will be analyzed in next section.

Table 4. Results about different tasks and flatcars.

T	F	NSGA-II			MOTS			NSGAII-MOTS		
		f	e	t	f	e	t	f	e	t
10	2	122.45	463.06	0.50	137.12	458.12	0.64	122.45	463.06	1.74
20	4	229.16	1066.24	0.57	229.16	1046.72	2.74	229.16	1046.72	2.41
30	5	350.56	1501.45	0.53	350.56	1481.94	5.03	350.56	1481.94	4.51
40	5	442.80	3159.24	2.04	440.80	3138.11	3.10	438.80	3138.07	3.09
40	6	452.85	3163.93	2.44	451.18	3164.14	4.48	451.18	3159.04	2.92
50	6	469.97	3480.68	2.74	458.30	3474.87	3.92	456.97	3472.85	3.74
50	8	481.08	3523.45	2.88	479.41	3518.20	3.90	473.41	3513.78	9.24

NSGA-II has a strong global search ability, but it is easy to fall into a local solution. The tabu search algorithm relies on the tabu list, and has the ability to jump out of local solutions. Meanwhile, different methods of constructing neighborhood also increase the diversity of neighborhood space, which has a good solution effect and a fast convergence speed.

The comparison of results in Table 4 can draw the following conclusions:

a) With the increasing of problem size, MOTS can obtain a better Pareto solution set than NSGA-II in the same iteration times;

b) When the scale is small (T= 10,20), both MOTS and NSGAII-MOTS can obtain the better results. When the scale is large, such as T = 40, the solution effect of the hybrid algorithm is significantly better than NSGA-II.

From the perspective of algorithm convergence, further compare the solution quality of the three algorithms. Taking $T20F4$ as examples, the relationship between the two objective function values and the iteration times is shown in Figure 5,6. It is clearly observed that NSGA-II has not converged in the set iteration times for 20 tasks, while for MOTS both two targets have converged at the 30th generation, and the hybrid algorithm has converged at the 60th generation. Within the iteration times set by the algorithm, both MOTS and hybrid algorithms can obtain better objective function values.

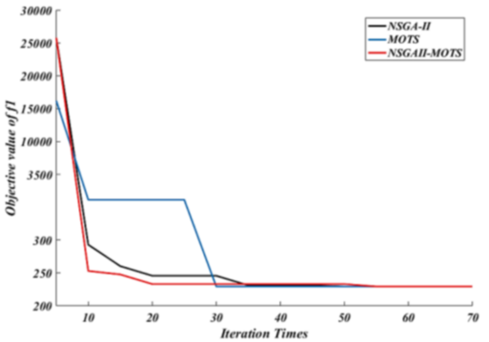

Figure 5. Convergence analysis of objective f.

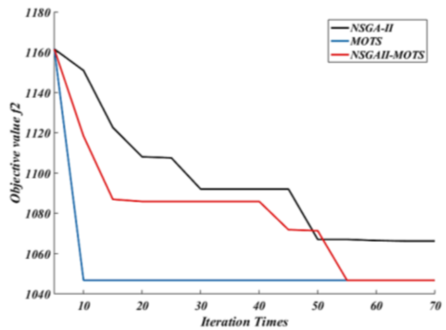

Figure 6. Convergence analysis of objective e.

4.2. Real-word case study of emission reduction benefits

Taking the actual scheduling task of a shipyard in Shanghai as an example, to verify the feasibility and effectiveness of the MILP model and hybrid algorithm proposed in this paper. The number of tasks is 40.We chose $T40F6$ dataset, while the detail of NO.7,8,9,13,14,15 flatcars is in Table 5. Randomly chosen one in Pareto set for example, the scheduling results is shown in Table 6,7.

Table 5. Task list for T20 and Flatcars information.

Task ID	Start	End	Time Window		Weight	Task ID	Start	End	Time Window		Weight	Flatcar ID	Load-Capacity
			Earliest	Latest					Earliest	Latest			
1	P6207	T1101	0	120	238	11	P6207	T1125	50	200	220	1	200
2	T1805	T1301	0	120	244	12	CBW	FAP	50	200	222	3	200
3	P6207	PW	0	120	264	13	P6207	PW	50	200	226	5	200
4	P7101	PW	0	120	276	14	CBW	SAW	50	200	226	6	200
5	P7107	FAP	0	120	280	15	P7107	FAP	50	200	242	7	250
6	T1805	SAW	0	120	283	16	P7314	T1125	100	220	258	8	270
7	P6207	SAW	0	120	283	17	P7511	CBW	100	220	276	9	325
8	P6207	PW	0	120	288	18	P7314	Yard	100	220	400	13	380
9	P6207	FAP	0	120	400	19	P6207	T1101	100	220	319	14	380
10	P6207	FAP	0	120	220	20	T1805	P7314	100	220	326	15	425

Table 6. Obtained task sequence results for each flatcar.

Flatcar NO.	Flatcar ID	Task Sequence	Non-value-added Time(min)	Carbon Emission(g)
1	7	32→21	451.18	3159.04
2	8	12→1→15→16→22→31→33		
3	9	6→8→7→10→25→35→27		
4	13	34→24→29→36→37		
5	14	14→5→4→13→26→17		
6	15	2→9→3→11→19→20→18→30 →23→28→38→40→39		

Table 7. Obtained route planning for flatcar NO.4.

Task ID	Flatcar NO.	Task Actual Start Time/min	Flatcar route planning (represented by intersections)
24	4	270.0	P7101-13-14-15-16-11-6-Painting Workshop
29	4	311.6	P6207-13-8-9-10-Final Assembly Platform
34	4	250.0	Curved Block Workshop-4-2-Processing Yard
36	4	350.0	P7314-13-14-15-16-11-6-T1125
37	4	391.3	P7511-13-14-15-16-11-6-4- Curved Block Workshop

According to the latest EU emission standards in early 2019, heavy cargo trucks are required to reduce CO2 emissions by 30% by 2030. Calculated based on the average workload of 2km per time, heavy fuel truck fuel consumption of 25.9L / 100km, and fuel emission factor of 2.621kg / L, the comparison of the optimal scheduling emission obtained in this paper and standard emission is shown in Table 8. We can conclude that the optimization of carbon emissions can meet the latest emission reduction standards.

Table 8. Carbon emissions comparison.

Standard Emission(g)	Generated Emission(g)	Decrease Percentage
8146.07	3159.04	61.22%

5. Conclusion

In order to actively respond to the call of green shipbuilding in China and achieve a high efficiency and low energy consumption transportation scheduling mode, we propose a bi-objective mathematical model for OVOC transportation scheduling problem, and design a NSGAII-MOTS algorithm. The NSGA-II and NSGAII-MOTS have different advantages according to the numerical results. The NSGA-II is competitive in computation time and can find Pareto solution for small-scale instances. However, the NSGAII-MOTS is absolutely competitive in terms of solution effect and convergence speed, and is suitable for optimizing large-scale and complex instances. The non-value-added time of 6 flatcars is reduced to 8h/day and carbon emission reduction benefits are obvious with the decrease percentage of 61.22%.

Based on the developed methods, the following practical features can be further studied to improve the applicability of the algorithms. (1) Two synchronizing flatcars transport one overweight segment can be considered, the corresponding coding method and time update mechanism are adjusted accordingly. (2) The road interference exists during the transportation of flatcars. Some roads can only travel with one flatcar at the same time. (3) Advanced computing technologies, e.g. cloud computing, can be used to improve the computation speed. (4) In order to highlight the application value of transdisciplinary engineering, we can consider introducing knowledge-based scheduling method, which can store knowledge in different fields to assist in scheduling decisions.

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A Multi-Criteria Approach for FMEA in Product Development in Industry 4.0

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Abstract. In Industry 4.0, current trends on data analysis and real-time processing are intertwined with the use of development tools while conceiving products. The quality of information plays a pivotal role in this process, as the heterogeneity of unprocessed data may result in issues that increase the product's cost and development time. In this context, the Failure Mode & Effect Analysis (FMEA) is a tool that aids decision-making by presenting pre-processed useful data that can improve product design, maintainability and manufacturing. FMEA criteria, although standardised, has ramifications that have different impacts and weight in an organisation, which might end up resulting in subjective evaluations. To cope with this issue and improve the quality of the information in product development, this research proposes a Multi-Criteria approach to define the importance of FMEA criteria and their impacts in organisations in a real industrial scenario. This research is applied using a case on a Brazilian electronics manufacturer, using AHP and TOPSIS Multi-Criteria Decision Making (MCDM) methods. Findings show that by traditional methods different evaluators end up generating different data and weights on FMEA, resulting in different results. In this sense, the application of the Multi-Criteria methods ends up ranking the importance of criteria and evaluating the inputs from all departments, returning more precise information. Furthermore, the weighting scale of FMEA has been shifted to a customised scale for the organisation in the study, based on AHP, more suitable to their needs and following their perception, to support the decision-makers most assertively.

Keywords. Industry 4.0, FMEA, Multiple Criteria Decision Making, AHP, TOPSIS.

Introduction

In the era of Industry 4.0 transformation, sensors, machines, workpieces, and IT systems are connected to improve the value offered while optimizing resources and decreasing development time. To apply such technologies, enterprises rely significantly on the quality of data to improve their decision-making process. This data has to be gathered and analysed, but the focus usually is on the analysis stage while the gathering and pre-processing are neglected often and might contain imprecise information due to: poor gathering process, the bias of collector or highly dynamic environments [1] [2] [3].

Currently, Product Development has increased the number of information necessary to improve its overall delivery quality and product's longevity in the market [4]. In this context, tools such as the Failure Mode & Effect Analysis (FMEA) offer ways of keeping development cycles active for longer and increasing focus on continuous improvement on products [5]. Despite its benefits to Product Development, the process of FMEA still relies heavily on the evaluators' opinion and might be affected by their position/function in an organisation, which might result in biased information that could be imprecise for sharing in an Industry 4.0 scenario [6].

This research has its focus on reducing bias on data gathering and analysis by offering a different approach that adds a Multi-Criteria Decision-Making (MCDM) approach to FMEA, to improve decision-making in a company, and, therefore, improving the quality of the information in a transdisciplinary environment such as the Product Development in Industry 4.0. The domains that are being approached in this research are depicted in Figure 1.

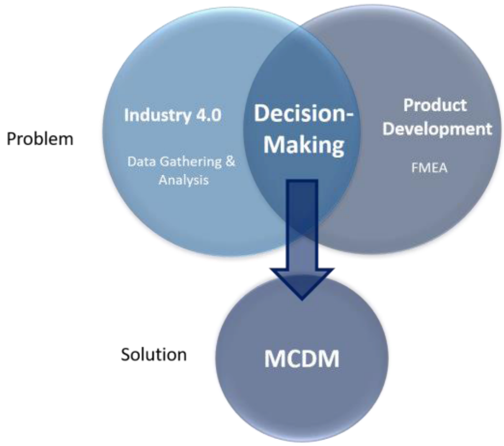

Figure 1. Domains of the Research.

As depicted in Figure 1, the "Problem" field of this research approaches the domain of Industry 4.0, more specifically the issues in its data gathering and analysis, and the issues of the FMEA tool in the Product Development domain. Both are related to the final quality of the Decision-Making Process. In another aspect, the "Solution" field of this research approaches the domain of MCDM, as ways of improving the quality of Decision-Making by reducing the bias of deciders.

1. Materials and Methods

This research main focus is to propose a multicriteria approach to define the failure modes importance of FMEA in an industrial scenario. To achieve this goal this research is considered to be of an applied nature, whilst its approach is considered qualitative. Finally, the technical procedures adopted to achieve the research objectives were a literature review on the conceptual background alongside an experimental case based on MCDM techniques.

Figure 2. Methodological Procedures.

The approach will be developed using MCDM algorithms to develop a different approach to FMEA with more consistent information and more accurate prioritisation.

The study will be validated through an experimental case, in which a FMEA application of a Switched-Mode Power Supply from a Brazilian electronics manufacturer will be scrutinized and compared considering the results before and after the application of the approach with MCDM.

2. Conceptual Background

2.1 Industry 4.0 and Data Gathering & Analysis

The current convergence and integration of new technologies in the field of manufacturing is being called "Industry 4.0" and refers to the Fourth Industrial Revolution, presenting remarkable differences concerning previous revolutions, which originally occurred within the factories and then left to be adopted by society, to a more holistic and integrated vision [7][8][9][10]. The basis of this vision relies significantly on data, which is generated in large volume, by various devices in industrial, commercial and residential environments.

Data is a valuable asset in the process of Decision-Making. In their “raw” form, through mining algorithms and other methodologies, they are processed to improve their quality, usability, accessibility and portability [11]. Once transformed, data is key to more agile and assertive decisions, a remarkable feature that denotes the ability to analyse and implement real-time changes required by the Fourth Industrial Revolution [8][12]. In this context, this new scenario requires higher quality and reliability of the information, where data is evaluated according to integrity, consistency, credibility, accuracy and clarity in its parameters, so that any analysis can discover models and patterns, relevant characteristics or trends in organisational historical records, the "Log of events" [13].

In another aspect, the original data collected are not properly analysed in early stages of decision-making, as they present bias, inaccuracy, redundancy, ambiguity, irrelevance, lack of pattern, manual collection, with heterogeneous interpretations, different meanings, use of personal language in its creation, and transcription failures [4][14]. Thus, its analysis is limited, having restricted interpretation, difficult understanding, and demanding excessive time for processing, hindering the extraction of knowledge and leading to inefficient solutions which compromise decision-making [4][15].

2.2 Failure Mode Evaluation & Analysis - FMEA

FMEA (Failure Mode Evaluation and Analysis) is a specific systematic methodology for identifying, evaluating and preventing problems in a product, system, project, process or service, through a risk analysis that considers the possibility of failures, risks and relevant impacts [6][16]. The methodology is used at various stages of a product's life cycle and serves the development team by identifying potential modes of failure based on previous experiences, minimising the impacts of risks and development time, as well as associated costs reduction [17]. Also, FMEA is an important strategic tool to extend product longevity and serves as a direction to improve products [5].

FMEA methods use the numerical risk priority value (RPN) as the product of three factors: Occurrence (O), Severity (S) and Detection (D), defined by the RPN formula = O x S x D, where for each variable a weight predefined by a qualitative scale is assigned [17]. The FMEA systems and projects have weights as shown in Table 1.

Table 1. Qualitative scale for FMEA.

Qualitative Scale	Severity (S)	Occurrence (O)	Detection (D)
1	No	Almost never	Almost certain
2	Very Slight	Remote	Very high
3	Slight	Very Slight	High
4	Minor	Slight	Moderately high
5	Moderate	Low	Medium
6	Significant	Medium	Low
7	Major	Moderately high	Slight
8	Extreme	High	Very Slight
9	Serious	Very high	Remote
10	Hazardous	Almost certain	Almost impossible

It is important to state that the literature emphasizes however that these weights and criteria are not a standard and may vary according to the experience of the FMEA team, and that it should consider specific factors for each project under study and analysis [6][16]. Furthermore, the literature points out that FMEA teams must be multidisciplinary and recommends working on its application in synchronicity [5].

Regarding the results of the implementation of FMEA, the team, in possession of the information and knowledge discovered from the analysis, should develop an action plan to mitigate risks and their impacts, evaluate and measure results and promote continuous process improvement, while considering the three risk factors (Severity, Occurrence and Detection) [17][18]. Literature points, however, that consensus on results might be influenced by the background of the evaluators of the FMEA team, which can create negative effects in and Industry 4.0 scenario by reducing reliability on data [1] [5] [6].

2.3 Multi-Criteria Decision Making Techniques

The original data collected in early stages of decision-making are quite often poorly analysed and this might result in negative effects in products and systems [4][14]. In this context, Multi-Criteria Decision Making (MCDM) can provide better data analysis so that companies can make more agile and assertive decisions, which is key for the Fourth Industrial Revolution. MCDM can provide an improved form of classification of data, expanding the cognitive capacity of the human being in his learning process, organizing the information, recognizing patterns, facilitating the deduction and completion, detecting the expected and discovering the unexpected [19][20].

This research approaches two Multi-Criteria Decision-making techniques. The first is the Analytic Hierarchy Process (AHP), and the second is the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS). Both can be combined to provide a more precise decision supporter in fields that require multiple views and considerations. The choice of those techniques is based on previous research, presenting the combination of AHP and/or TOPSIS as frequently used MCDM techniques, and their association with FMEA [5][6][19].

The AHP was developed by Thomas Saaty during the 70s and is a systematic method applied in unstructured problems with different decision-making situations, ranging from simple to complex [21][22]. AHP is divided into four main phases, being: (1) Structure the problem in hierarchical form; (2) Obtain the Judgemental matrix through pairwise comparisons; (3) Identify individual priorities and consistency of comparisons; and (4) Aggregation of the identified individual priorities.

TOPSIS was developed by Hwang and Yoon in 1981 and is a multi-criteria decision analysis method that compares and selects alternatives based on criteria and their respective weights, normalizing their scores and calculating distances between each alternative of ideas solutions, seeking the approximation of the positive solution and the removal of the negative solution. In other words, it is a technique for evaluating the performance of alternatives through the similarity of these with an ideal solution. In TOPSIS, the best alternative is the closest to the ideal solution compared to the others [19].

The method is divided into 7 steps; (1) Performance Matrix, (2) Normalization, (3) Weighted Standard Matrix, (4) Positive and Negative Ideal Solutions, (5) Positive Ideal Solutions (Si*) and Negative (Si'), (6) Similarity and (7) Ranking /Classification. Table 1 provides a summary of the TOPSIS model, bringing all the aforementioned steps and a description explaining each step and their formulae.

3. Approach for Multi-Criteria Decision Making for FMEA

In this research, the data from an already existent Product FMEA was used, applying the proposed MCDM approach to evaluate the impact of the selection of qualitative weights of the FMEA made by three expert evaluators of the project. The expected result was a change in the definition of priorities for the elaboration of the action plans. To improve the application of the MCDM methods chosen for FMEA, a spreadsheet tool containing AHP and TOPSIS algorithms was developed.

The product in the analysis is a switched-mode power supply, made by a Brazilian electronics manufacturer. The company uses FMEA for about six years and usually works with 3 to 6 evaluators from different departments and backgrounds on the same product (depending on the complexity of the product and time availability). In their procedure, evaluators define the failure modes in a group, filling, in sequence, the FMEA table on their own and later gathering again to compare their results to find a consensus, which demands time and may be influenced by the evaluators' background. For this application, the ten failure modes identified for the product were approached and analysed by the MCDM approach. A depiction of the approach is presented in Figure 3.

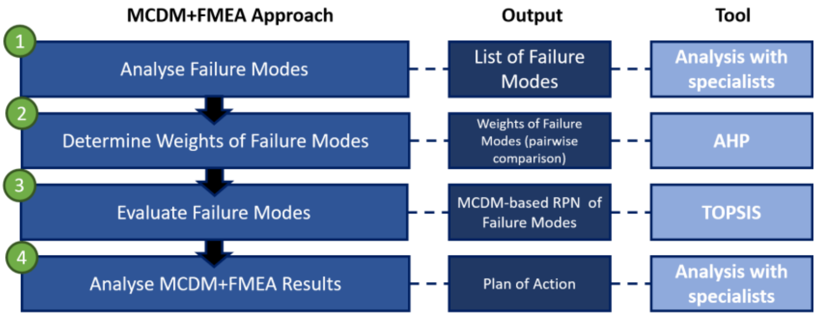

Figure 3. MCDM+FMEA approach.

The proposed MCDM approach for FMEA starts with an analysis of the failure modes of the product in study and ends by creating a plan of action to reduce the effects of failure modes. In this experimental case, both this analysis, represented by details 1 and 4 of Figure 3, were not developed, as the data input was an already existent FMEA, so both steps were already performed.

The determination of wights for FMEA was done using the AHP technique with all the three original evaluators, based on the preparedness of the R&D team to solve the failure mode, in terms of know-how (Detail 2 of Figure 3). The failure modes were compared using AHP, as depicted in Figure 4.

AHP WEIGHTS FOR FMEA		CR = CONSISTENT	Failure Mode 1 - RELAYS - Sticky contact	Failure Mode 2 - ACS SENSORS - Incorrect current measurement	Failure Mode 3 - DRIVE CARD - Incorrect switching	Failure Mode 4 - ACS SENSORS - Incorrect current measurement	Failure Mode 5 - ACS SENSORS - Incorrect voltage measurement	Failure Mode 6 - Harnesses / Terminals / Racks / Copper Bar / Connectors - Incompatible gauge	Failure Mode 7 - INDUCTORS - Reaction of varnish with resin	Failure Mode 8 - LEAKAGE SENSOR TO EARTH - Do not detect leakage current	Failure Mode 9 - INDUCTORS - Overheating	Failure Mode 10 - IGBTs MODULES - Overheating
CRITERIA/ ALTERNATIVES	CI (%)	9,572%										
Failure Mode 1 - RELAYS - Sticky contact	26,15%		1	3	5	3	5	3	5	3	3	3
Failure Mode 2 - ACS SENSORS - Incorrect current measurement	13,30%		0,33	1	1	3	1	3	1	3	1	5
Failure Mode 3 - DRIVE CARD - Incorrect switching	10,72%		0,20	1,00	1	1	3	1	3	1	3	1
Failure Mode 4 - ACS SENSORS - Incorrect current measurement	9,91%		0,33	0,33	1,00	1	1	3	1	3	1	3
Failure Mode 5 - ACS SENSORS - Incorrect voltage measurement	8,61%		0,20	1,00	0,33	1,00	1	1	1	3	3	1
Failure Mode 6 - Harnesses / Terminals / Racks / Copper Bar / Connectors - Incompatible gauge	5,99%		0,33	0,33	1,00	0,33	1,00	1	1	1	1	1
Failure Mode 7 - INDUCTORS - Reaction of varnish with resin	7,50%		0,20	1,00	0,33	1,00	1,00	1,00	1	1	3	1
Failure Mode 8 - LEAKAGE SENSOR TO EARTH - Do not detect leakage current	5,54%		0,33	0,33	1,00	0,33	0,33	1,00	1,00	1	1	1
Failure Mode 9 - INDUCTORS - Overheating	6,83%		0,33	1,00	0,33	1,00	0,33	1,00	0,33	1,00	1	3
Failure Mode 10 - IGBTs MODULES - Overheating	5,46%		0,33	0,20	1,00	0,33	1,00	1,00	1,00	1,00	0,33	1

Figure 4. AHP Pairwise Comparison.

The criteria went through a pairwise comparison, made with the company's evaluators, resulting in the judgemental matrix (Figure 4). The spreadsheet tool developed was used to apply the AHP method, calculating the consistency of the pairwise comparison. As depicted, in the view of the evaluators, the sticky contact is the failure mode which they are more prepared to solve in terms of R&D know-how. In the end, the application of the AHP returned the weight importance for each criterion, as depicted in Figure 5.

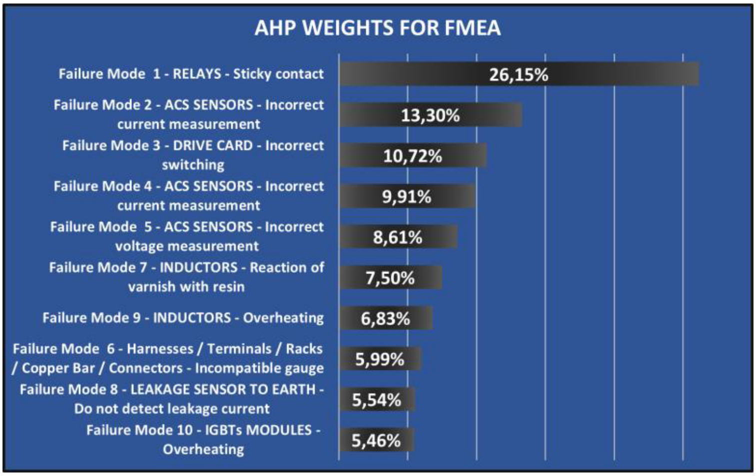

Figure 5. AHP weights on Failure Modes.

The weighting scale from AHP served as the basis for the application of the next step of the approach, the TOPSIS method (Detail 3 of Figure 3). The TOPSIS was organised regarding the Identified Failure, Priority Criteria (Severity, Detection, Occurrence), the weight of the criteria (from the AHP results), Minimum and Maximum Value of the scale (1 and 10, based on original FMEA), and Number of Evaluators (in this case, three). This step of the approach, in summary, adapts the FMEA calculation to the TOPSIS notation.

TOPSIS - MCDM Tool						
	IDENTIFIED FAILURES	FMEA Priority Criteria	Weight of Criteria	Qualitative Scale - Minimun Value	Qualitative Scale - Maximun Value	Number of Evaluators
1	Failure Mode 1 - RELAYS - Sticky contact	SEVERITY (S)	26,15%	1	10	Evaluator 1
2	Failure Mode 2 - ACS SENSORS - Incorrect current measurement	DETECTION (D)	13,30%	1	10	Evaluator 2
3	Failure Mode 3 - DRIVE CARD - Incorrect switching	OCCURENCE (O	10,72%	1	10	Evaluator 3
4	Failure Mode 4 - ACS SENSORS - Incorrect current measurement		9,91%	1	10	
5	Failure Mode 5 - ACS SENSORS - Incorrect voltage measurement		8,61%	1	10	
6	Failure Mode 6 - Harnesses / Terminals / Racks / Copper Bar / Connectors - Incompatible gauge		5,99%	1	10	
7	Failure Mode 7 - INDUCTORS - Reaction of varnish with resin		7,50%	1	10	
8	Failure Mode 8 - LEAKAGE SENSOR TO EARTH - Do not detect leakage current		5,54%	1	10	
9	Failure Mode 9 - INDUCTORS - Overheating		6,83%	1	10	
10	Failure Mode 10 - IGBTs MODULES - Overheating		5,46%	1	10	

Figure 6. TOPSIS - Input data for the tool developed.

Data from the product's FMEA, referring to the priority criteria of each identified failure (Severity (S), Detection (D), Occurrence (O)) and Risk Priority Value (RPN) were inserted into the spreadsheet tool, followed by the evaluation of each member of the evaluators separately, per failure mode and based on the available FMEA, as depicted in Figure 7.

Failure Mode 1 - RELAYS - Sticky contact	EVALUATORS		
	Evaluator 1	Evaluator 2	Evaluator 3
SEVERITY (S)	10	9	8
DETECTION (D)	5	5	5
OCCURENCE (O)	4	4	4
RPN	200	180	160

Failure Mode 2 - ACS SENSORS - Incorrect current measurement	EVALUATORS		
	Evaluator 1	Evaluator 2	Evaluator 3
SEVERITY (S)	7	8	9
DETECTION (D)	6	6	6
OCCURENCE (O)	4	4	4
RPN	168	192	216

Failure Mode 3 - DRIVE CARD - Incorrect switching	EVALUATORS		
	Evaluator 1	Evaluator 2	Evaluator 3
SEVERITY (S)	7	5	6
DETECTION (D)	5	5	5
OCCURENCE (O)	3	3	3
RPN	105	75	90

Failure Mode 4 - ACS SENSORS - Incorrect current measurement	EVALUATORS		
	Evaluator 1	Evaluator 2	Evaluator 3
SEVERITY (S)	7	7	8
DETECTION (D)	6	6	6
OCCURENCE (O)	2	2	2
RPN	84	84	96

Failure Mode 5 - ACS SENSORS - Incorrect voltage measurement	EVALUATORS		
	Evaluator 1	Evaluator 2	Evaluator 3
SEVERITY (S)	10	9	8
DETECTION (D)	4	4	4
OCCURENCE (O)	2	2	2
RPN	80	72	64

Failure Mode 6 - Harnesses / Terminals / Racks / Copper Bar / Connectors - Incompatible gauge	EVALUATORS		
	Evaluator 1	Evaluator 2	Evaluator 3
SEVERITY (S)	3	5	6
DETECTION (D)	5	5	5
OCCURENCE (O)	5	5	5
RPN	75	125	150

Failure Mode 7 - INDUCTORS - Reaction of varnish with resin	EVALUATORS		
	Evaluator 1	Evaluator 2	Evaluator 3
SEVERITY (S)	7	7	6
DETECTION (D)	5	5	5
OCCURENCE (O)	2	2	2
RPN	70	70	60

Failure Mode 8 - LEAKAGE SENSOR TO EARTH - Do not detect leakage current	EVALUATORS		
	Evaluator 1	Evaluator 2	Evaluator 3
SEVERITY (S)	7	6	7
DETECTION (D)	3	3	3
OCCURENCE (O)	3	3	3
RPN	63	54	63

Failure Mode 9 - INDUCTORS - Overheating	EVALUATORS		
	Evaluator 1	Evaluator 2	Evaluator 3
SEVERITY (S)	7	8	8
DETECTION (D)	2	2	2
OCCURENCE (O)	4	4	4
RPN	56	64	64

Failure Mode 10 - IGBTs MODULES - Overheating	EVALUATORS		
	Evaluator 1	Evaluator 2	Evaluator 3
SEVERITY (S)	7	8	7
DETECTION (D)	2	2	2
OCCURENCE (O)	3	3	3
RPN	42	48	42

Figure 7. TOPSIS – FMEA data from the three evaluators for each identified failure.

Furthermore, the general classification of priorities was obtained associating FMEA with the MCDM approach, considering the combinations of all three evaluators' analysis. The objective was to identify the impact on classification for the evaluators, both individually and in groups, and thus be able to infer if the MCDM approach for FMEA presents a significant difference in results on the final order of prioritisation with and without MCDM. The results are shown in Figure 8.

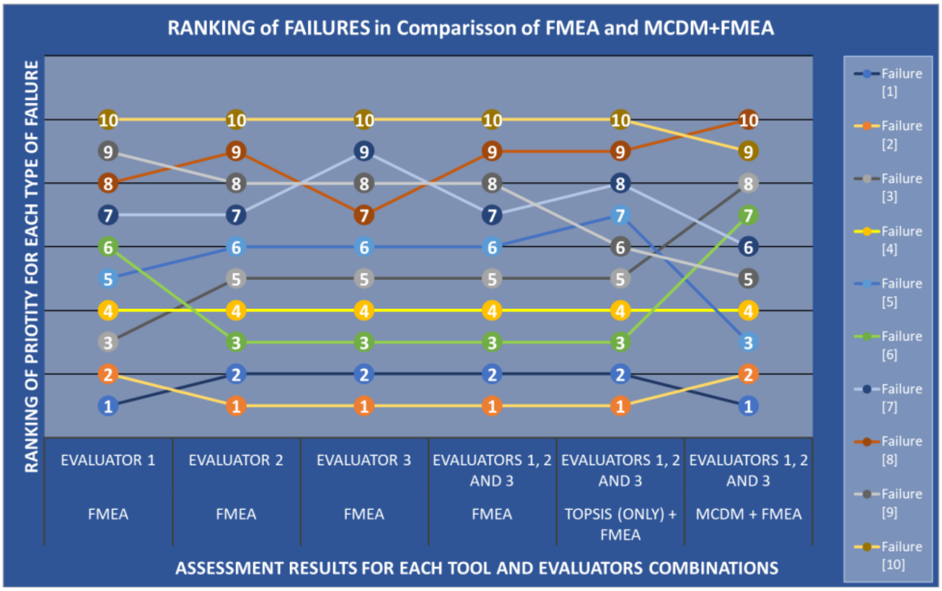

Figure 8. Comparison of Methods.

The ranking differences in Figures 8 represent the divergence regarding the evaluators' considerations when applying FMEA and their considerations with the application of the MCDM approach. When considering the final ranking provided by the application of the MCDM techniques, there are significant differences regarding the results from the evaluators applying only FMEA. The application of both MCDM techniques resulted in a significant change in the final results. To improve comparison TOPSIS alone with the FMEA evaluation was represented as well, providing changes on the final results of FMEA as well.

4. Results and Discussion

Through the application of AHP and TOPSIS in association with FMEA, it was possible to note a difference between evaluators from different departments and the overall order of relevance of failure modes. In this sense, AHP and TOPSIS could work as a mediator to improve the decision-making, avoiding the necessity of discussion and consensus between evaluators (which can be time-consuming) in the final results of FMEA, providing an improved approach that can work as a basis for new FMEA applications.

In the literature review of the conceptual background, other approaches associating FMEA with MCDM methods were found, but with some differences regarding scales, application field and mostly the different methodologies to provide weighing scales. In Bian [6], for instance, authors changed the weight system by including D-Numbers, to reduce uncertainty when weighting FMEA for application of the TOPSIS. This research opted by using the regular scale and attributing weights based on AHP results, as the focus of the research resides in creating an approach to FMEA based on MCDM techniques.

The AHP application made easier to establish the importance for each of the Failure Modes in the vision of the company's specialists. In this sense, this customizable scale for different scenarios may improve overall decisions on criteria and the results of applications with other MCDM techniques. The AHP weighting based on the company's preparedness to solve failure modes provided a major impact on the results, overall.

The application of the TOPSIS method in the FMEA process of the company ended up by improving the process in terms of agility, by reducing the discussion on weighting, scales and the consensus of final values. As a result of this process, a change in the process was suggested by evaluators, by elaborating forms for each of them and processing the results through the TOPSIS tool, ending up on a more robust FMEA for the company's R&D team.

As for the final results of the MCDM approach for FMEA, it is possible to see that the techniques' implementation has a significant impact on the final results of the FMEA. This occurs due to an improved definition of the criteria relevance concerning each other, which improve the prioritisation of action plans. The results show that differences between evaluators are more easily coped when the MCDM techniques are used, as their algorithm can cope with different evaluators. It is possible to infer that the application of the MCDM techniques provides a more precise prioritisation on FMEA, as subjectiveness and possible bias of evaluator are reduced.

5. Conclusion

The proposed multi-criteria approach was able to improve and better represent divergent visions on FMEA, reducing heterogeneity in interpretation, subjectiveness, and bias in the evaluation process, while creating a new standard for the company's R&D.

The approach provided an improved FMEA experience for product developers, and have the potential to become a day-to-day part of other operations while improving standardisation and the documentation of process indirectly.

Further works are related to the development of professional tools for MCDM and FMEA, as well as other Product Development Tools and MCDM techniques. Furthermore, it is suggested that an integrated platform of MCDM and Product Development Tools would improve the Product Development Process.

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Application of MCDM in the Earlier Stages of the PDP

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Abstract. The market demands have pushed the industries to create products to be more innovative and with less time to launch. This situation pressures the entire product life cycle, from its design and manufacturing to the delivery to the market, requiring greater speed and precision in each of these phases. The first stage of the cycle affected by this trend is the development of new products, an interactive, complex engineering and decision-making process. In this sense, it is necessary to know the main agents and actors involved in this process of developing new products and how they interact with each other so that, with this understanding, it is possible to determine the main uncertainties to be mitigated within the earlier stages and avoid potential risk for the subsequent phases of the PDP. By using the PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluation) and GAIA (Geometrical Analysis for Interactive Aid) methods, this paper proposes a comparative model selecting the main components of the product development process, indicating how the interaction between them may minimize the uncertainties in the earlier stages of the PDP.

Keywords. Product Development Process, Multiple Criteria Decision Making, Impact Analysis, Agents

Introduction

The product development process (PDP) can be thought of as a comprehensive and continuous process, where the project is progressively detailed through a series of phases, many of them interdependent with each other and with a high volume of information generated throughout the process. In addition, as development progresses and consolidates, changes become more difficult, from the point of view of costs, reallocation of resources, impacts on schedule among others. Thus, agents and assumptions adopted early in the development phases are critical to the success of the project, determining the direction of the project [1].

The activity of pondering and selecting from a myriad of agents which will be the most impacting and determinant for the success of the work, depends on project to project and under what conditions they will be executed. As selection and evaluation of these agents may have a degree of subjectivity and uncertainties involved, decision-makers often need assistance in selecting the most satisfactory alternatives. Thus, an effective knowledge and an early evaluation of these agents, with their uncertainties and impacts, become essential elements for the sequence in the execution of new

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product development projects. Once these agents are not effectively identified and addressed, they can lead the project to delays, failures, budget compromise and profitability, and often until cancellation. On the other hand, determining agents that are keys to success, and potentializing their applications, can bring powerful competitive advantages. It is important to emphasize that early evaluations do not replace the subsequent project risk management with the applicable tools. It is also observed that there is a detachment of the final stages of the development cycle (prototyping, testing, simulation and optimization) for the initial stages (product definition, product planning, conceptual design), in which the work takes place in levels of abstraction. A number of studies and experiences motivates this shift, according to which decisions taken in the early stages of product development are those that produce the greatest impacts on total cost and product quality. For example, according to Nordlund's (1996) survey, about 80% of the total cost of a product is defined by the end of the conceptual design step [2].

According to [3], product development is a deliberate business process involving hundreds of decisions, from the generation and selection of ideas to commercialization, and one of the critical steps in this process is the conceptual design of the product being created. In [4], the authors state that approximately 85% of problems with new products can be attributed to a poor design. Therefore, nothing is more sensible than seeking optimization in this conceptual phase of the product, which involves identifying agents of greater relevance for decision making, how they relate to each other (interactions) and, consequently, impact on success from the project. Some of these agents may have non-measurable goals, such as reducing complexity or increasing adherence to project requirements (qualitative requirements). Situations such as these lead to the existence of links between decision data for the main solutions to be adopted. Determining how to qualitatively analyze the interactions between decision makers and to address combined actions of the main solutions is a problem that must be solved. Thus, this research applies multicriteria decision making method to determine uncertainties and impacts among the main agents involved in the earlier stages of the Product Development Process. Given that products will tend to be designed with higher quality and lower costs, it is expected that society's needs and desires will be met more effectively and promptly.

1. Technological Background

Among these various MDCM methods, the MAUT (Multi-Attribute Utility Theory), whose main advantage is that it takes into account uncertainty. Has seen heavy applications in economic, financial, actuarial problems, water management, and energy management and problems agricultural activities. A similar method in popularity to MAUT is the AHP (Analytic Hierarchy Process), whose main feature is the use of paired comparisons - pairwise comparisons, which are used both to compare the alternatives with respect to the various criteria and to estimate the weights of the criteria [5].

Another method that has been applied is the Fuzzy Set Theory, which is an extension of classical set theory that "solves many problems relating imprecise and uncertain data" [6]. Fuzzy Theory has been used in applications in the fields of engineering, economics, environment, medical and management.The Data Envelopment Analysis (DEA) uses a linear programming technique to measure the relative efficiencies of alternatives [7] and has as one of the main characteristics the possibility of dealing with multiple inputs and outputs.

Another method applied is the ELECTRE, based on the analysis of concordances and that has the advantage of taking into account in the analysis the uncertainties and inaccuracies in the decision-making. ELECTRE has already been used in energy, economy, environment, water management and transportation issues. The TOPSIS (Technique for Order Performance by Similarity to Ideal Solution) method has an approach of identifying an alternative that is closer to the ideal solution and further away from the ideal negative solution in a multidimensional computing space "[8]. TOPSIS has been used in supply chain management and logistics, design, engineering and manufacturing systems, business and marketing management, environmental management, human resources management and water resources management.

Finally, the PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluation) method has become quite popular due to its simpler mathematical properties and ease of use [9]. An important aspect is related to the ease of decision makers to understand the concepts and parameters inherent in the method, which simplifies the preference modeling process and, consequently, increases the effectiveness of the multicriteria method application. PROMETHEE has had much use in environmental management, commercial and financial management, chemical, logistics and transportation, manufacturing and assembly, energy management and agriculture. In function of its ease of application and because it is able to establish standard relations (preference function) between criteria that are not comparable to each other, the PROMETHHE method was the chosen option for the sequence of this work.

1.1. The Promethee Method

The methods PROMETHEE I and PROMETHEE II were developed by were developed by [10] and presented for the first time in 1982 at a conference in Canada. Some years later [11] developed the methods PROMETHEE III (ranking based on intervals) and PROMETHEE IV.

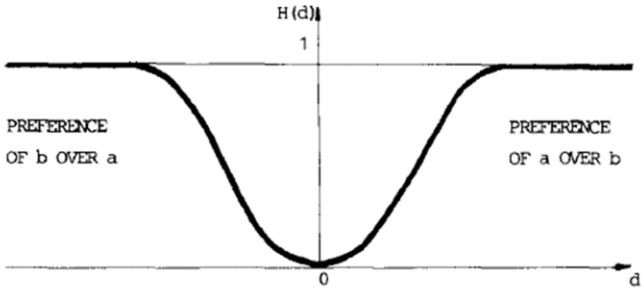


Figure 1. Function of Preference.

In 1992 and 1994, these same researchers also suggested two extensions of the method, PROMETHEE V (MCDM including segmentation constraints) and PROMETHEE VI (a representation of the human brain). The PROMETHEE method is an interactive MCDM approach designed to deal with both quantitative and qualitative criteria with discrete alternatives. In this method, a pairwise comparison is performed to calculate a preference function H for each criterion, as can be seen in Figure 1.

Function of Preference. Based on this preference function, a preference index for an alternative "a" over an alternative "b" is determined. This preference index is the measure to support the hypothesis that the "a" alternative is preferred over "b". Thus, the PROMETHEE method can create evaluation standards for alternatives that are not comparable to each other [12].

In a first phase of the method an outbound relationship is constructed between a discrete list of criteria. At this point, a preference index is defined and a preference chart is obtained. In a second phase, based on the graphs of preference, an exploration of each adopted criterion is made: a partial preorder (PROMETHEE I) or a complete preorder (PROMETHEE II) in the set of possible actions, in order to reach the solution of the problem.

1.2. Criteria for applying the PROMETHEE method

The PROMETHEE methods can only be applied if the decision maker can express his preference between two actions in a given criterion in a scale ratio:

- The preference function fj for a criterion j returns, for a difference d between two evaluations on this criterion, a value fj (d) ε [0,1]. This value is a real value on a ratio scale. Therefore, the decision maker may express the magnitude of his preference between actions of a certain criterion.
- The PROMETHEE methods can only be applied if the decision maker can express his preference between two actions of a criterion in a certain scale:
- The PROMETHEE methods need quantifiable criteria of importance, that is, weights, on a scale of proportion. Therefore, a decision maker should be able to provide such quantitative or qualitative measures with the necessary precision. The decision maker it should also be aware that a criterion with eg 1.8 weight is twice as important as a criterion weighing 0,9 to calculate a value that expresses the outranking ratio.
- The PROMETHEE methods can only be used with criteria where the differences between the evaluations are significant - the preference function, as defined in the PROMETHEE methods, is transforming a difference between two evaluations of a criterion into a real value (between 0 and 1). This is not a problem for criteria with range or ratio scale. For criteria with an ordinal (or nominal) scale, the difference has no mathematical significance.

The partial pre-order PROMETHEE I and the full pre-order PROMETHEE II are based on a global comparison between actions. With this, adding or deleting actions after the construction of the preference function can compromise the overcoming relationship.

2. Method to determine uncertainties and impacts among the main agents involved in the earlier stages of the Product Development Process

2.1. Conceptualization and modeling

Product design is an iterative, complex, and decision-making engineering process. It usually begins with identifying various needs, proceeds through a sequence of activities to find an optimal solution to the problem, and ends with a detailed description of the product. Generally, a development design process consists of three phases: product design specification, conceptual design and detailed design [13][14].

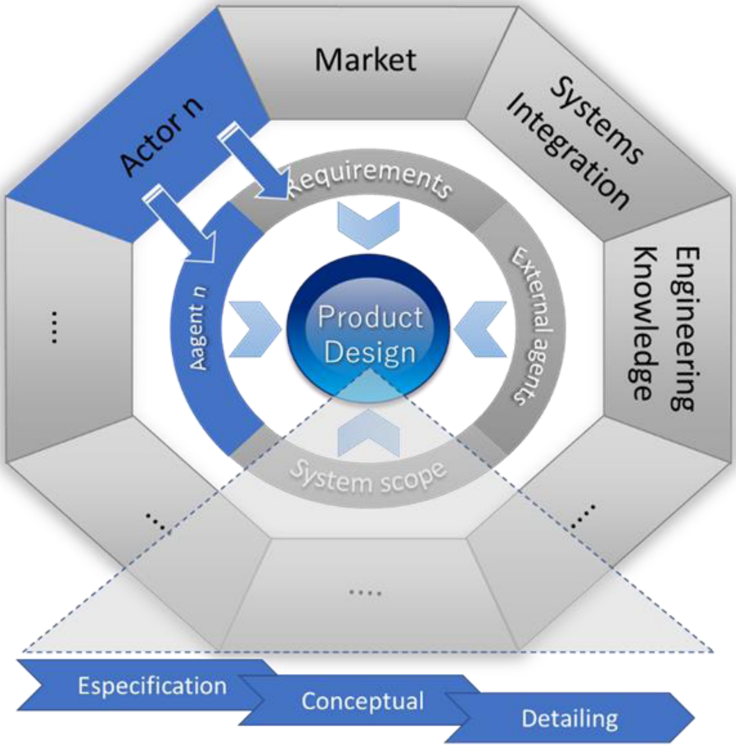


Figure 2. Product Design Model.

During these phases, several agents directly influence the execution of the project, determining priorities, risks, resource allocation and others. Acting on these agents there is the action of several actors, who well determined and controlled will determine the success or failure of the acting of these agents during the project. Figure 2. Product Design Model illustrates how this relationship occurs.

2.2. Determination of the agents of the development process

According to [15], requirements statements are written with the various stages of product life in mind and determining the appropriate requirements at each stage. With this, the quality of the product is perceived as all the functional requirements of a product are met.

For simple or complex systems, a basic principle used in analysis is to divide and conquer. This means seizing the entire system, partitioning it into subsystems (components), and then trying to understand each subsystem (component) and its relationships (external and internal) [16]. In this way, factors external to the organization can influence the functional and specific advantages of the project, compromising the organizational implementation capacity and the launching of new products. In addition, since the conceptual design of the product development is decomposed into subsystems and components, the agents related to them must be evaluated to understand how they act together (adherence to product requirements).

Exchanging information between dependent and interdependent design tasks can also cause design rework, because downstream starts early using immature information from an upstream task. Therefore, upstream progression could cause downstream rework. [17]. That is, the information relations between all activities in the product development process are perceptible or predictable [18] and result in successive iterations in the various stages of development, which may alter the understanding and the progress of the work already performed.

The project also goes through several tasks: from the clarification of the project objectives, establishing its function, generating alternative incorporation projects that meet these specifications, defining the attributes of the function, evaluating these alternatives and considering the ergonomics and material selection. That is, in the process of product development it is necessary to structure and record how concepts and knowledge must be synthesized in order to support a design situation.

2.3. Relationship between agents in the development process

In turn, these agents interact with each other in a non-linear way throughout the development cycle, and their outputs directly influence the performance of the other agents. This interaction is presented in Figure 3.

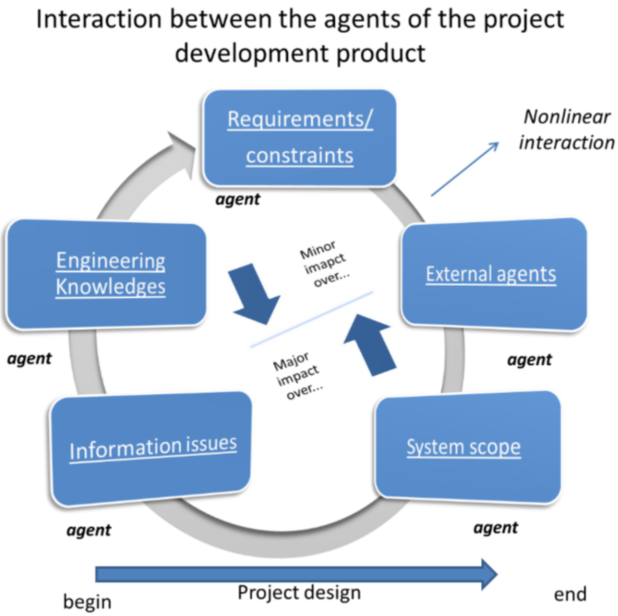


Figure 3. Agents Relationship.

2.4. Reduction of uncertainties in the development process

As changes and uncertainties during the development process must be controlled and reduced, it is important that the following design situations be optimized:

- Requirements changes during the product development project should be minimized to reduce rework over the project scope.
- Influences of external agents should be minimized to keep project complexity in check.
- The decomposition of the subsystems should be organized in such a way as to maximize the adherence of the requirements throughout the development of the project.
- The sharing of the information generated during the execution of the work must be maximized in order to reduce rework or redundancy of efforts and activities.
- The application of Engineering knowledge must be maximized in order to improve the development time of the product in its conceptual phase.

2.5. Determination of actors in the development process

These effects of maximization or minimization are caused by the action of the various actors inherent in the development process. For the purpose of the construction of the model that will be proposed, the following actors were considered, which were extracted from the following research: [19], [20],] [21], [17], [22].

- Market: defines the market where the product is inserted. For example: submarine, space, energy, wind etc. [19];
- Initial design phase: related to how decisions taken in the early stages of development [20];
- Decomposition of systems: considers the level of system-wide subsystems [21];
- Integration of systems: related to how the subsystems interact with each other [17];
- System interface: related to how the subsystems interact with each other;
- Project decision making: related to how design decisions are spread across development teams;
- Project information management: related to how information generated during development is managed;
- Uncertainties of design parameters: related to the level of uncertainty of information produced during development [22];
- Engineering Methods: related to engineering knowledge applied during development.

2.6. Construction of the model

Considering that the actors are critical success factors for the execution of the development project, it is necessary to determine the degree of their relevance in relation to all agents identified during the development process. Thus, having this construction, it will be possible to determine which actors should be treated in more detail in order to reduce uncertainties throughout the product development project.

Applying these rules in the Promethee method would have the following model, as Figure 4. Promethee Model:

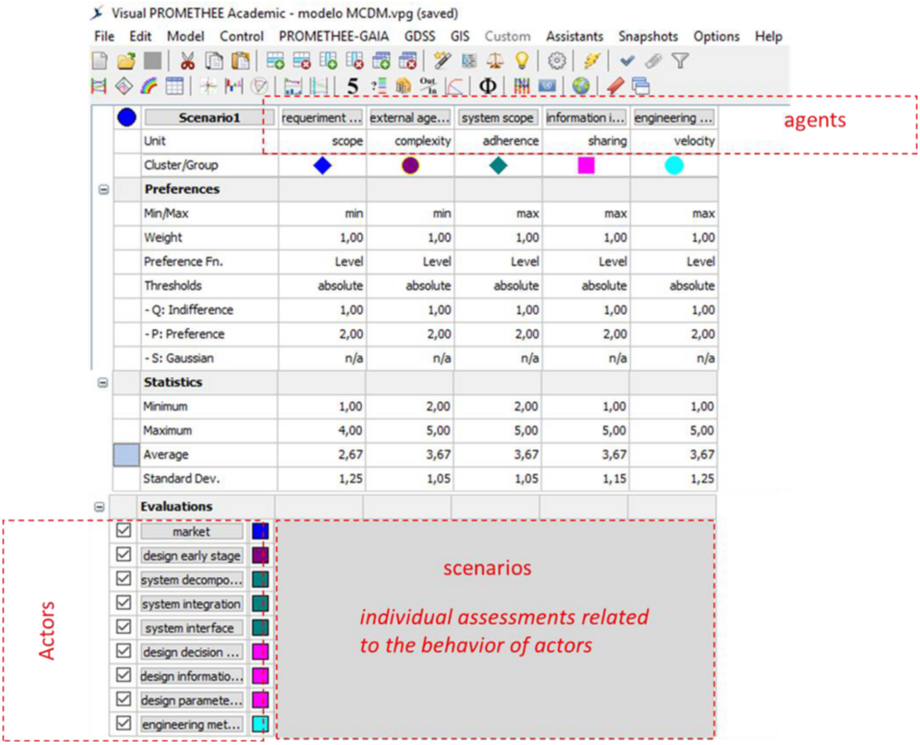
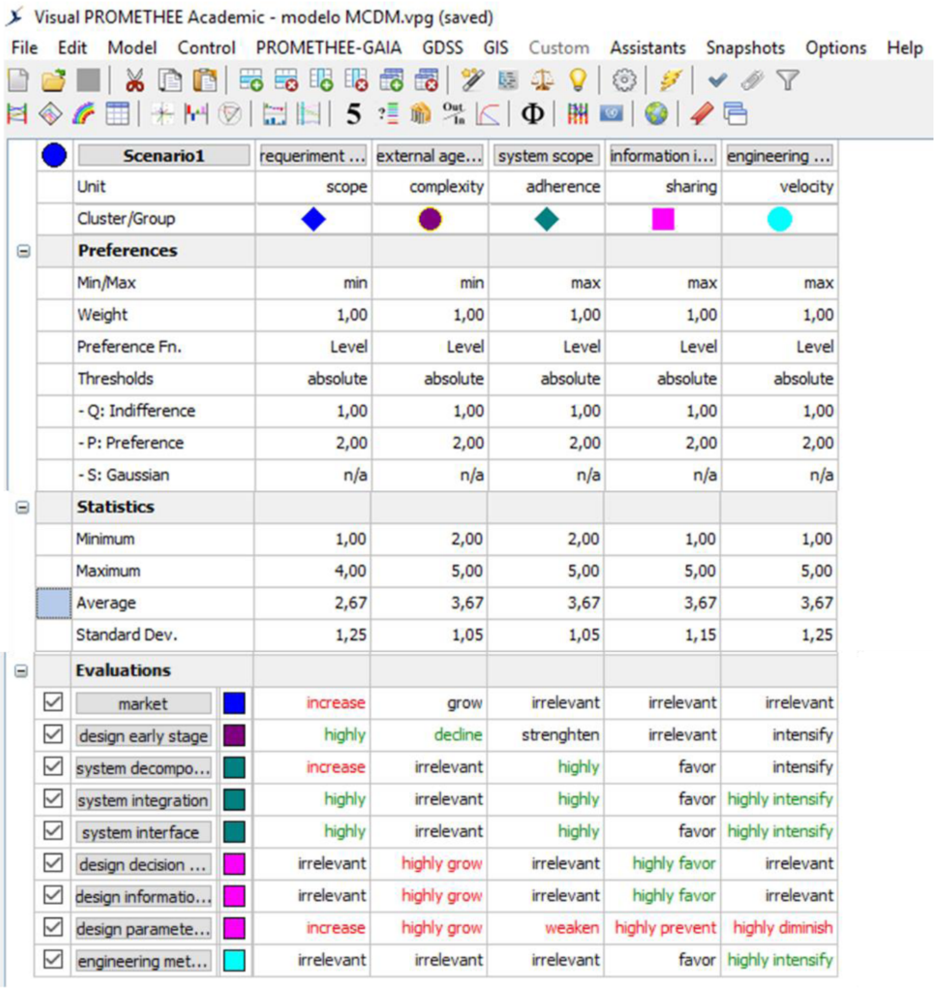


Figure 4. Promethee Model.

3. Experimentation

The proposed model was tried in a scenario of development of a product / system of high complexity. Complex products or systems are deployed in a variety of contexts of use, under a large number of different conditions. They also have a behavior that is difficult to predict in some circumstances. Many of these products have a long service life and are upgraded or adapted during their lifetime. They are usually designed by a large number of people, often in different locations and distributed through a large supply chain. Unlike much simpler consumer products, these products typically have only a small number of competing products that can be used as guides for system design [18]. Considering the outlook for the oil and gas industry in the coming decades:

- Exploration of oil and gas happening in more inhospitable regions;
- More people living in cities than in the countryside (more demand for energy);
- Despite recent advances, alternative sources of energy have not fully proven their viability for economic growth, with costs higher than oil;
- High dependence on the petrochemical industry;
- Predicted increase in world oil production for the next 20 years (source: Deloitte Marketpoint World Oil Markets), the evaluation of the behavior of the actors was based on the scenario of development of complex petroleum products in submarine beds. Thus, with these premises, the experimental model was thus constructed, as Figure 5.



Scenario1	requeriment ...	external age...	system scope	information i...	engineering ...
Unit	scope	complexity	adherence	sharing	velocity
Cluster/Group					
Preferences					
Min/Max	min	min	max	max	max
Weight	1,00	1,00	1,00	1,00	1,00
Preference Fn.	Level	Level	Level	Level	Level
Thresholds	absolute	absolute	absolute	absolute	absolute
- Q: Indifference	1,00	1,00	1,00	1,00	1,00
- P: Preference	2,00	2,00	2,00	2,00	2,00
- S: Gaussian	n/a	n/a	n/a	n/a	n/a
Statistics					
Minimum	1,00	2,00	2,00	1,00	1,00
Maximum	4,00	5,00	5,00	5,00	5,00
Average	2,67	3,67	3,67	3,67	3,67
Standard Dev.	1,25	1,05	1,05	1,15	1,25
Evaluations					
market	increase	grow	irrelevant	irrelevant	irrelevant
design early stage	highly	decline	strenghten	irrelevant	intensify
system decompo...	increase	irrelevant	highly	favor	intensify
system integration	highly	irrelevant	highly	favor	highly intensify
system interface	highly	irrelevant	highly	favor	highly intensify
design decision ...	irrelevant	highly grow	irrelevant	highly favor	irrelevant
design informatio...	irrelevant	highly grow	irrelevant	highly favor	irrelevant
design paramete...	increase	highly grow	weaken	highly prevent	highly diminish
engineering met...	irrelevant	irrelevant	irrelevant	favor	highly intensify

Figure 5. Experimental Model.

highly decrease	highly decline	highly weaken	highly prevent	highly diminish
decrease	decline	weaken	prevent	diminish
irrelevant	Irrelevant	Irrelevant	Irrelevant	Irrelevant
increase	grow	strenghten	favor	intensify
highly increase	highly grow	highly strenghten	highly favor	highly intensify

Figure 6. Possible Range Entries.

4. Discussion of the result

By applying the method (Figure 7), it is observed that knowing the market where the product is inserted, the actions of project information management and the uncertainties of design parameters are of great relevance in the process of product development . In this way, if the effects of these are not mitigated properly, this can jeopardize the success of the development. For the other actors, the deviations are discrete and do not justify specific actions.

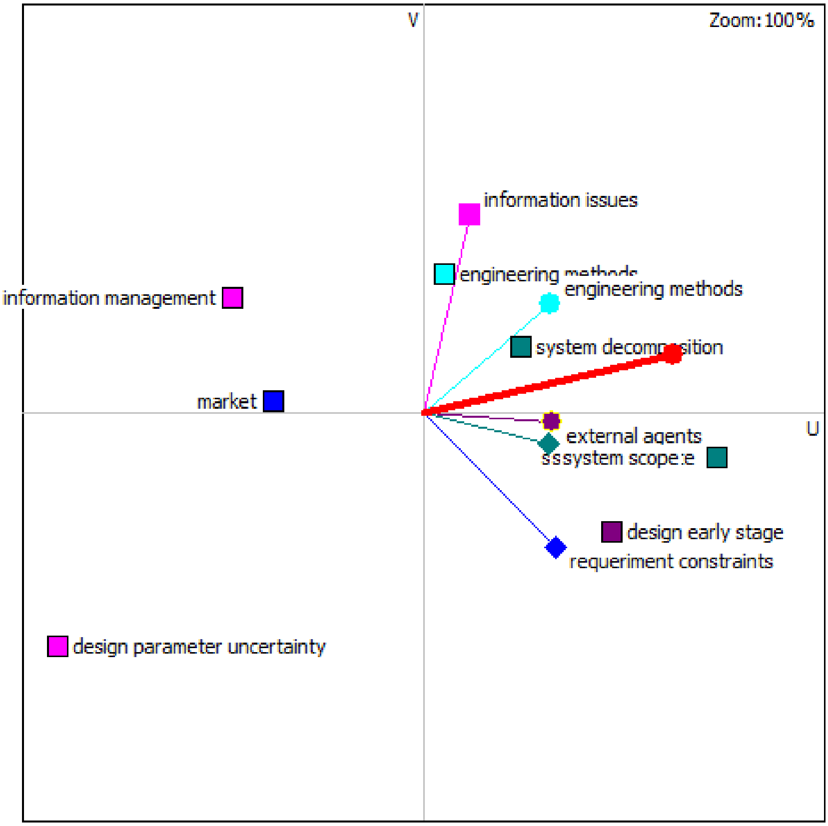


Figure 7. GAIA Analysis.

Considering that in a product development process the number of variables and their possibilities of variation is very large, the proposed model can visually and easily interpret to indicate which of these variables (called here of actors) are those with greater possibility of impact in the development.

It is important to note that there may be variations in the results, given that the model is very dynamic and may vary depending on the market where the product being developed is inserted, the profile and experience of those involved in the ranking of the entries. Therefore, in order to reduce these variations it is recommended that the participants of the evaluation act in the same market and have similar experiences in relation to the product being developed.

The scientific work, involving the application of MDCM methods in the field of product development process, approaches themes with the selection of better design concepts [1], selection of maintenance strategies [23] and selection of materials, designers and manufacturing processes [24]. Thus, the proposed model has a degree of novelty, given that it addresses the identification and mitigation of uncertainties in the development process.

5. Conclusions

The present work aims to propose a model based on MCDM (Multiple-Criteria Decision Making) that helps identify among the main agents of the product development process (PDP), which present the highest degrees of uncertainty and, therefore, must have effective mitigating actions.

In order to reach this goal, a bibliographic review was initially made to identify the main studies and their contributions related to the objectives of the study. The research fields covered the MDCM, Concurrent Engineering, Systems Engineering, Project Management and Risk Management methods. From the compilation of some important concepts, it was possible to create a generic conceptual model that was able to relate the main agents and actors that act in a PDP, and how the interaction between these elements affects the development process.

The great scientific contribution of the present work is its novelty in relation to a great challenge in the process of product development, (aplicable within the Product Engineering disciplines such as Mechanical, Mechatronic, Electronic and Software),which is to identify already in the first phases of the process which elements present the greatest potential of uncertainties, and consequently of risks, for the of the development project. Another important collaboration is that the output of the model will be a reliable input for the risk management of the development project. In addition, because it is a generic model, it can be applied in different markets, for different types of product.

A limitation observed in this construction is related to the accuracy of the results. As it is based on the evaluations of the individuals involved in the process, it is necessary to be judicious in the selection of the contributors for the formation of the data mass. The applicability of the model can be considered as a minor limitation: it is aimed at the development of complex products, involving a large number of variables and difficult predictability of how they will behave throughout the work.

The sequencing of this work provides a link to the risk management of product development projects, as the identified and perceived uncertainties at this stage of development are likely to be potential risks later on. This work also presents another front for future research, related to the management of interfaces between subsystems that composes the development of complex products.

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Evaluating Smart PSS Solutions with Context-Awareness in Usage Phase

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Abstract. With the mature development of IoT techniques, smart PSS emphasizes the digital transformation of the traditional PSS, which is an ever-evolving and value-co-creation system with the participation of users through the whole product lifecycle, especially during the usage stage. Due to the frequent changes of usage situations, the smart PSS providers are supposed to evolve their product-service bundles according to the trends of usage situations. It is critical to determine what is the current uasge situation, thereafter to evaluate and select proper product-service bundles during the usage phase. In this article, we propose a context-aware approach to evaluate the smart PSS performance during the usage phase.

Keywords. Product-service systems, Smart Product-Service System (Smart PSS), solution evaluation, sustainability, context-awareness

Introduction

In the era of digitalization, the traditional manufacturing companies have been looking for the way to extend their business scope to a integration of both physical products and intangible services, i.e. Product-service systems (PSS) [1]. PSS has the essential features that it is a multi-dimensional system including various actors and diverse product-service bundles [2], making the evaluation of PSS a challenging task. As Mourtzis, et al. [3] stated, PSS evaluation approaches were not be fully explored since lots of emphases were given to the design methodology of PSS. Only about one fifth (18%) related academic researches have mentioned the importance of PSS evaluation from 1999 to 2016 [3]. Furthermore, only a small portion of companies can get a profit in their business transformation [2]. One of the challenges of the PSS development is to make sufficient evaluation with the consideration of diverse stakeholder's interests before and after launching it to the market.

Furthermore, with the mature development of IoT techniques, a new paradigm of PSS, i.e. smart PSS, has appeared [4]. It emphasizes the digital transformation of the traditional PSS, which is an ever-evolving and value-co-creation system with the participation of users through the whole product lifecycle, especially during the usage stage [5]. However, due to the frequent change of the usage situations, the smart PSS

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providers are supposed to evolve their product-service bundles according to the changes of usage situations [6, 7].

Facing to the above problems of complex system evaluation and the change of usage situations, it is critical to determine the current usage situation for a user and thereafter select proper product-service bundles during the usage phase. In this article, we proposed a context-aware approach to evaluate the smart PSS performance during the usage phase. The rest of this paper is organized as follows. Section 1 discussed the existing studies about smart PSS and solution evaluation in the field of PSS. The proposed context-aware smart PSS evaluation method is described in Section 2. Then we give an illustrative example of evaluating the performance of an online 3D printing rent website in Section 3. Finally, the conclusions are summarized in Section 4.

1. Literature review

1.1. Smart PSS and context-awareness in smart PSS

Smart PSS is a multi-disciplinary and integrated system containing smart products/services, various stakeholders and associated platform, which was firstly proposed by Valencia Cardona, et al. [4]. The term ‘smart’ generally means the ability of making smart/wise decisions based on the data from networked smart products and services for generating/upgrading the functionalities [8]. Compared with the traditional PSS, it emphasize several features in the literature, such as high degree of autonomy [8] (e.g., real-time reaction [8] and context-awareness [4]), high connectedness [9], degree of personalization [9] and value-co-creation [10].

Particularly, the importance of contexts has been highlighted in providing correct value propositions or functionalities by the participants of a survey [4]. More specically, the end-users are expecting unique rather than generalized functionalties which are dependent of contexts from the smart PSS teams. A context can be defined as any information that can be used to characterize the situation of an entity [11]. An entity is a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and applications themselves . In this study, the contexts refer to the end-users’ usage situations instead of the design process situations. Following the idea of context-awareness in smart PSS, the service providers are expected to upgrade their functionalities or give rapid reactions once the contexts of the end-users change.

1.2. Solution evaluation in PSS

The assessment of PSS is usually measured by key performance indicators (KPIs) in terms of the diverse evaluation objectives for different stakeholders [2]. According to the indicators used in the evaluation process, PSS can be evaluated from three perspectives, including customer, sustainability, risk and so on [3].

As for the indicators based on customer perceptions, the studies mainly focus on the early design stage. Kimita, et al. [12] have identified PSS features with relation to customer satisfaction and proposed a non-linear satisfaction-attribute (S-A) function to quantify customer satisfaction. Lee, et al. [13] concentrated on assessing the probability of acceptance of new PSS concepts by users. Analytic Network Process (ANP) and Niche Theory were used by them to quantify customer acceptance. Though lots of evaluation tools have been tested and used, the evaluation of PSS is still non-comprehensive by considering the process with only one type of stakeholder (i.e. customers) simply. Furthermore, the other phases of PSS, such as manufacturing, logistic and especially usage phase, are omitted.

Another perspective in PSS solution evaluation focuses on sustainability, which is the hotspot in recent studies. It assesses PSS from three dimensions of environmental, social and economic aspects [14], thus making the evaluation more comprehensive. Sun, et al. [15] studied the interrelationships between the PSS's provider and accepter (i.e. customers) and thereafter designed five factors to evaluate the product-service performance, including time, quality, cost, stability and reliability. Similarly, an evaluation scheme for PSS was designed by Kim, et al. [16] considering both providers and the customers as well. The evaluation criteria contain profitability, planet, people, quality and cost.

Other studies also discussed the influence of risk. Abramovici, et al. [17] introduced an indicator framework to monitor the PSS in the usage phase. In their framework, product quality (such as reliability, stability), service quality (such as service reliability, service assurance, responsiveness) and cooperation quality have been considered.

Based on the reviewed literature, the performance or quality evaluation of PSS mainly concentrates on the indicators of the customer perceptions in the early design phase and manufacturing process before launching PSS provision to the market. However, smart PSS intends to achieve smart decisions and automatic actions based on various scenarios, a context-aware solution evaluation approach in usage phase is still lacking. The research questions that how to justify the usage scenarios in smart PSS and how to evaluate the possible solutions based on the context information still remains to be explored.

2. Methodology

This section describes the overall context-aware smart PSS evaluation approach with details, including the context modeling in PSS and the solution evaluation framework. In the first half, the context features will be predefined by experts/engineers, their patterns will be extracted and categorized as diverse scenarios. Afterward, compared with the conventional PSS evaluation approach conducted in the early design stage, a context-aware solution evaluation module is added and studied.

2.1. Context modeling and scenario identification

The basis for context-aware applications is a well-defined context model [18]. Based on the widely accepted context model defined in [19], three core steps are designed to adapt context-awareness into smart PSS, namely (1) predefine the context features of interest; (2) identify the scenarios of interest and (3) detect scenarios of interest. In this research, we follow the key steps of building up a context-aware system, as shown in Figure 1.

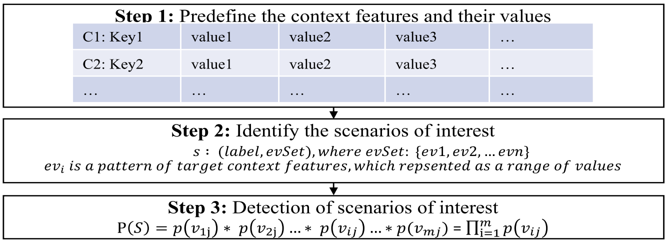

Figure 1. An overview of the context modeling and scenario identification.

2.1.1. Predefine the context features of interest

To achieve context-aware applications, it is necessary to define the involved entities with the variables and relationships in the environment [20]. Key-value modeling [21] is applied to represent each context features. A context feature can be defined as a set which has a key and the set of possible values, denoted as

$$C_i = (key, \{v_1, v_2, \ldots\}). \quad (1)$$

The aggregation of context features can be expressed as a set of context features from various context categories, which is denoted as $\mathrm{C} = \{C_1, C_2, \ldots, C_m\}$ where m means the number of context features. The concept of semantic relations R, as defined in [19], is used to identify the relationship/behaviors among the context features. For example, some semantic relations can be defined as

<3DPrinter, hasModel, productModel>

<3DPrinter, hasSensor, nozzleTemperature>,

<3DPrinter, is locatedAt, location>,

<User, isLocatedAt, location>

<UserA, hasPreference, productModel>

2.1.2. Identify the scenarios of interest

After defining the context models and their relationship, it is possible to identify scenarios of interest in smart PSS. A scenario refers to the current situation of the product-service bundles and its involved environment, which can be represented as a tuple with its label and a set of events [20]. A mathematical expression of the scenario is

$$s: (label, evSet) \quad (2)$$

, where $evSet$ refers to the set of one or more predefined contexts with values, that

$$evSet: (C_1: v_1, C_2: v_2, \ldots, C_n: v_n) \cap Relation\{C_i\}. \quad (3)$$

2.1.3. Detect scenarios of interest

The scenarios are classified as default scenarios and deflected scenarios in this approach. The default scenarios are preset in the smart PSS that the designers/engineers assume them will happen with a certain pattern while user using the product-service bundles, while the deflected scenarios are the ones whose event sets have been changed from the default scenarios to other patterns.

In this step, we intend to judge whether an unlabeled scenario is deflected or not. Given a new unlabeled scenario, we would like to identify either it belongs to a predefined scenario or not based on its context features' values. Here we set the probability of context feature C_i's value appearing in positive scenarios as $p\left(v_{ij}\right)$. Each involved context features may have their own probability distribution, such as Bernouli distribution, binomial distribution, Poisson distribution, normal distribution and so on With the assumption that context feature is independent with each other, the probability of a scenario is a positive one can be computed by using the following equation:

$$\mathrm{P}(S) = p\left(v_{1\mathrm{j}}\right) * \ p\left(v_{2\mathrm{j}}\right) \ldots * \ p\left(v_{ij}\right) \ldots * p\left(v_{mj}\right) = \prod_{\mathrm{i}=1}^{m} p\left(v_{ij}\right) \quad (4)$$

, where *Si* is the unlabelled scenario, v_{ij} is the *j*-th value of context feature C_i appearing in a positive scenario. If $\mathrm{P}(S)$ is larger than the threshold ε, then it is a default scenario that is initially desired by the users. Otherwise, it belongs to a deflected scenario.

2.2. Solution evaluation framework

If a deflected scenario is detected, solutions should be evalauted based on the interests of both the users and service providers/manufacturers, then the proper solution will be selected to response to the scenario change. The evaluation objective and the evaluation indicators need to be identified.

Inspired by the concept of customer value (CV) which is formulated by Reidenbach [22], denoted as $CV = \frac{Utility}{Cost}$, a novel evaluation objective, i.e. stakeholder value (SV) which expands the evaluation scope to measure the total utility of smart PSS with the consideration of interests of both customers and manufacturers, was proposed. It is the objective function for the aim of maximizing the value/interest of both customers and manufacturer/service providers. To achieve it, five relative evaluation criterion are defined as follows.

1. maximize the smart PSS quality ($\boldsymbol{Q}$);
2. minimize the cost ($\boldsymbol{C}$);
3. maximizing the customer satisfaction ($\boldsymbol{CS}$);
4. maximize (at least remain) the sustainability ($\boldsymbol{S}$) of smart PSS platform; and
5. maximize the value-co-creation ($\boldsymbol{VCC}$) capability.

Hence the abovementioned objective function $\boldsymbol{SV}$ can be formulated as

$$SV = \frac{w_1 * Q + w_2 * CS + w_3 * S + w_4 * VCC}{C} \quad (5)$$

Smart PSS quality (*Q*). Initially, the quality characteristics which affect the functions of smart PSS should be identified. Those characteristics can be selected among the context features from the preliminary work. For example, the nozzle flow rate of the 3D printers is one of the context features and simultaneously a quality characteristic affecting its functional performance as well. The selection of appropriate quality characteristics requires solid engineering knowledge about the products and/or services under investigation. After identifying the quality characteristics, Taguchi's quality loss function [23] is applied to calculate the functional performance for each quality factor. Based on different types of expected quality factors' value, the functional performance can be evaluated as follows.

$$L(x) = \begin{cases} kx^2, x \text{ is the smaller the better} \\ k(x-m)^2, x \text{ is nominal} - \text{the best} \\ k\frac{1}{x^2}, x \text{ is the larger the better} \end{cases} \quad (6)$$

, where $L(x)$ is the loss function, K means the quality loss coefficient, x is the quality characteristic and m refers to the expected value when the quality loss is nominal the best. The total quality loss can be calculated as the accumulation of all the quality loss values, i.e. $L_t(X) = \sum L(\text{x})$. The total functional performance of a product-service bundle can be determined by

$$Q = 1 - \alpha L_t(X) = 1 - \alpha \sum L(x) \quad (7)$$

, where α is the regularisation coefficient to standardise the value of Q within the range of 0–1.

Customer satisfaction (*CS*). A five-point scale ranging from 'dissatisfied' to 'satisfied' is applied to derive customer satisfaction. Here, we focus on the increment of the customer satisfaction value after a solution is provided to the user. To standardise the CS indicator, the CS is defined as $\text{CS} = \frac{\Delta CS}{CS_0} = \frac{CS_1 - CS_0}{CS_0}$, where CS_0 is the original customer satisfaction level and CS_1 is the customer satisfaction level after receiving a certain solution. The customer satisfaction data can be collected through historical questionnaires on similar product-service bundles.

Sustainability (*S*) of product-service bundles. This study concentrates on the environmental effect together with the economic effect, especially the extended lifespan of product-service bundles and the cost of part reusability in the closed-loop of smart PSS. The sustainability of a product-service bundle in a smart PSS is expressed as

$$sus = \frac{\sum \Delta\, lifespan_i}{\sum lifespan_i} \quad (8)$$

, where $lifespan_i$ means the lifespan of a product-service bundle in the i-th loop. It can be obtained from the manufacturer/factory of each product modules, which are tested before the product modules are moved to the next factory. The numerical values for $\Delta\, lifespan_i$ can be obtained from the service provider during the operation of the product-service platform. The variable sus indicates the sustainability capacity of a product-service bundle in several update loops, from the perspective of value-in-use retention capacity and extended lifespan.

Value co-creation (VCC) measurement through interaction and personalization. The foundational premises addressed in the S-D logic literature [24] have addressed that value is co-created by multiple actors, including the beneficiary, moreover, value is always uniquely and phenomenologically determined by the beneficiary. Hence, the measurement of value co-creation is related to the interaction between actors (e.g. users and service providers) and the personalization. In this paper, since we focus more on the generated values with the participation of users, only two attributes are adopted to measure the value co-creation capability of smart PSS, i.e., the interaction between users and stakeholders, and personalization. We describe it with the following function:

$$vcc = interaction + personalization \quad (9)$$

$$interaction = \frac{no.of\ interactions}{no.of\ interaction\ channels} \quad (10)$$

$$personalization = \frac{no.of\ personalized\ parts/modules}{no.of\ total\ parts/modules} \tag{11}$$

Besides the evaluation indicators, the weights of the evaluation indicators are case-by-case in different PSS application domains. For example, the weights in the aeroplane services are different with the ones in vehicle rent. Usually, the weights in a certain PSS application domain will not change frequently, thus they can be predefined by the experts or obtained through survey from a group of users before the smart PSS solution evaluation. Once triggered by the deflected scenarios, the smart PSS solution can be evaluated according to the described equations considering the needs of multiple stakeholders. The larger the *SV* is, the better the performance of the solution will be.

3. An illustrative example of remote 3D printing system

This section utilizes a remote 3D printing system which mainly offers the online 3D printing services and associate services (e.g., 3D printer phase recommendation and discussion forum) as an illustrative example to validate the feasibility of the proposed approach. The 'smartness' of this example is reflected in the automatic scenario identification and the solution process once the scenario changes. In this example, an individual user whose usual behavior is ordering the 3D printing services online regularly and intermittently (default scenario) is set as the given user.

3.1. Context modeling and scenario identification of the remote 3D printing system

For the described scenarios, several context features are collected and summarized in Table 1. The value boundaries of each context features are decided based on the domain knowledge which collected from a 3D printing website: 3dhubs.com.

Table 1. Context features and their values of the remote 3D printing system.

Context feature No.	Context feature name (key)	Values of context features
C1	printFrequencyMonthly	{1:0-5; 2:10-25; 3: >=25}
C2	printDurationOneTime	{(0,1) :<5h; (1,0) :>=5h}
C3	modelSize	{(0,1): <=400*400*400mm; (1,0) :> 400*400*400mm}
C4	user	{(0,1): new user (time after registration is less than 3 months); (1,0): regular user (else)}

At the same time, the semantic relations between the defined context features include but not limited to:

<*user, hasPreference, printFrequencyMonthly* >

<*modelSize, identify, printDurationOneTime* >

The value of *modelSize*, *printFrequencyMonthly* are decided by users. The value of *printDurationOneTime* is represented by the *modelSize*, while the model is still offered by the users themselves. Based on the context features and their relations, one default scenario and two deflected scenarios of interest are represented in Table 2, including '*Regular printing intermittently*', '*Frequent printing*' and '*Long continuous printing*'.

Furthermore, the scenarios depend on three context features, i.e. *user*, *printFrequencyMonthly* and *printDurationOneTime*. Their value ranges and decision boundaries are predefined as Table 3 shown. The probability distribution functions of them are defined as follows. Context feature *user* follows a sigmoid function, *printFrequencyMonthly* and *printDurationOneTime* follow the Poisson distribution.

$$\mathrm{P1} = \mathrm{P}\{\mathrm{C4} = (0,1)\} = \frac{1}{1 + e^{-(-t+3)}}$$

$$\mathrm{P2} = \mathrm{P}\{\mathrm{C1} = \mathrm{k}\} = \frac{17^{k} e^{-17}}{k!}$$

$$\mathrm{P3} = \mathrm{P}\{\mathrm{C2} = \mathrm{k}\} = \frac{2.5^{k} e^{-2.5}}{k!}$$

In this way, the probability of a scenario is a default scenario can be calculated as

$$\mathrm{P(default\ scenario)} = P1 * P2 * P3$$

The threshold was set as 0.05 since the involved scenarios will not significantly cause a breakdown or other security accidents that need a lower threshold.

Table 2. The scenarios of interest.

Scenario No.	Scenario name	evSet	Pattern	Scenario type
S1	Regular printing intermittently	{ev1}	{user: (1,0) ∩ printFrequencyMonthly: 2 ∩ printDurationOneTime: (0,1)}	Default usage scenarios
S2	Frequent printing	{ev2}	{user: (0,1) ∩ (printFrequencyMonthly: 1 ∪ printFrequencyMonthly: 3) ∩ printDurationOneTime: (0,1)}	Deflected usage scenario
S3	Long continuous printing	{ev3}	{user: (0,1) ∩ (printFrequencyMonthly: 1 ∪ printFrequencyMonthly: 3) ∩ printDurationOneTime: (0,1)}	Deflected usage scenario

Table 3. Default values or intervals and optimal values for the involved context features.

Context features	Default values	Default intervals	Optimal values
user (time length after registration, month) (C4)	New user:(0,1)	0-3	/
printFrequencyMonthly (times) (C1)	Regularly:2	10-25	17
printDurationOneTime (h) (C2)	Less than 5h:(0,1)	0-5	2.5

3.2. Solution evaluation of the remote 3D printing system

During the usage phase of the remote 3D printing system, if the usage scenarios are detected deflected from the default scenario (i.e. S1 : Regular printing intermittently), some certain solutions should be conducted. Assume that two solutions are the alternative solution, namely *Recommend user to buy a printer* and *Recommend user to change parameters.*

According to the equation (5), we can evaluate the two solutions, as shown in Table 4. Each evaluation indicators are evaluated and normalized into a range of [0,1]. Though a survey of the 3D printing experts and end-users, the weights of the evaluation indicators were derived as [0.29, 0.37,0.21,0.13]. Table 4 shows the values of each evaluation indicators for each solution. The results indicate that given scenario 2 (S2), Solution 2 (Sol1) has a higher SV value, meanwhile give scenario 3 (S3), Solution 3 (Sol3) has the higher SV value.

Table 4. Evaluation results of short-term solutions.

	Sol1: Recommend user to buy a printer	Sol2: Recommend user to change parameters
S2	Q = 0.508, CS =0.893, S=0.581 VCC =0.526, C=0.881 SV = 0.762	Q = 0.239, CS =0.117, S=0.320, VCC =0.181, C=0.283 SV = 0.711
S3	Q = 0.087, CS =0.346, S=0.559, VCC =0.081, C=0.881 SV = 0.317	Q = 0.887, CS =0.510, S=0.903, VCC =0.645, C= 0.283 SV = 2.528

4. Conclusion

Though lots of studies have discussed the evaluation of PSS, context-awareness as one of the unique features of smart PSS has not been deeply discussed. The contributions of this work are summarized as follow. First, this approach defined the manner of both context features and scenarios in smart PSS, meanwhile offered an operable approach to justify whether a scenario has changed or not. The approach of context modeling and scenario identification serves as a foundation in smart PSS to assist the decision-makings in further design activities, making the solution evaluation more autonomous. Furthermore, a novel evaluation objective SV was proposed. It expand the evaluation scope from just customer value to the value of both customers and stakeholders, making the smart PSS be more sustainable and value-co-created.

Except for the contributions, the limitations of this research appeared as well. The decision boundaries of context features now depend on the domain knowledge, which need to be set by experts manually. A decision boundary learning approach remains further study.

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System Properties to Address the Change Propagation in Product Realization

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Abstract. Demanding markets and complex products are only some of the reasons that make changes and variations inevitable through different stages of product realization. From early phases of product development to downstream production phase, these changes or variations cause failure either directly or by propagating to other phases, triggering more fluctuations like the well-known butterfly effect. In this paper, first, the definition of changes in product realization will be reviewed and then different papers and their classification on change related system properties (illites) will be discussed and compared. It was argued that considering a system-level view, one could trace these propagations in the systems as a result of not being robust, flexible, or adaptable, etc. Some of the ambiguity in this semantic field demonstrated and most repeated definitions are identified as the unanimous and agreed-upon definitions in the literature. In the end, a historical comparison of the three identified properties presented. The results of this study help us to understand the multidisciplinary nature of these propagations and identify their stemming turbulent environment. This will be used as a foundation for forthcoming research either to prevent these propagations or utilize their attributes in the product realization.

Keywords. Changes in product realization process, Change propagation, Chaotic behavior, Adaptable, Flexible, and Robust design, Product design and development, Mass customization

Introduction

Product realization is a transdisciplinary field of research that has one goal, and that is to fill out the requirements based on constraints or to be more precise, to address stakeholder's preferences [1]. The fundamental characteristic of these preferences is that they change. Regulations, innovative technologies, stakeholder's dynamic preferences, and complexity in product architecture lead to changes or a series of changes [2] sometimes addressed as propagation in the literature. A research project named Butterfly Effect has recently started in Jönköping School of Engineering to study and exploit these change propagations. The name comes from chaos theory by Edward Lorenz [3] that argues that unpredictable changes will prevent forecasting the occurrence of tornados in the future of our systems. This paper is the very first stage in this project aiming to clarify the research, find a suitable direction, and review the literature in a broader system view. Since the project has started newly, and no interviews have done with companies. This paper lies with the ontological and theoretical framework rather than industrial case

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analysis. Therefore, the scope of this paper does not cover producing a chaos model and defining attractors, but such information can be a topic of future studies. Lorenz studied chaos in complex product family shape and its multiple composition factors [4].

Nonaka in his famous book [5] argued that changes in product and production design should be welcomed. Thus, changes and their propagations could have positive effects by creating opportunities to practice lean design or lean manufacturing and increase efficiency, or indeed they can have a negative effect and be a threat, triggering other changes, resulting in rework or longer lead time [6]. For example, Stolt et al. [7] talk about three companies with ETO business models that need supports for customization and easy adaptation to fluctuating requirements during the course of a development project. And [8] address this by acknowledging change as a normal condition and developing means to efficiently re-design and assess the impact of changes by adopting means like set-based concurrent engineering.

Propagation starts with a change. For example, making small changes in the product model could cause large and unexpected effects on the production system. Or vice versa, making changes in the production system may cause large and unpredicted effects in what can be offered to the customer through the product model [9]. To understand change propagation in product realization, the first logical step is to take a closer look at the change itself in a generic way and elaborate on what change means. Therefore, this paper will look at the broader picture with a system engineering [10] approach. System engineering is a transdisciplinary tool that focuses on the development of functionality in the early phases, based on customers' needs and requirements which continues into synthesis and validation [11]. Lifecycle properties or system properties, which sometimes are called ilities, aid designers with the right alternatives for stakeholders' preferences [12]. The transdisciplinary nature of this paper and the Butterfly Effect project is highlighted here when considering a wide range of disciplines involved, from product development to production and from system engineering to the computer science field.

The purpose of this paper is to find change-related system properties and a consensus definition for them in literature and identify the trend for future research in our research project. Therefore, this paper presents a review of change-related system properties and argues that Flexibility, Adaptability, and Robustness are the most used properties (ilities) that the majority of authors have agreed on them and use them for changeability in system level. Moreover, a historical comparison of the these most used ilities illustrates that recently Robustness is getting high recognition form scholars in this field.

1. Literature review methodology

Changes in product realization have been studied from many perspectives. Design for change is one such viewpoint that first proposed by [13] and entails several properties that together they offer the concept of changeability throughout the system lifecycle. Changeability in a complex system is an attribute that prevents change propagations [14] and preserves stakeholders' preferences. These properties are sometimes called ilities and have a very diverse range. Table 1 shows one basic classification for these properties.

Table 1. Change-Related and Architecture-Related ilities Examples [15].

Change-related ilities	Architecture-related ilities
Adaptability, Flexibility, Reconfigurability, Agility, Changeability, evolvability, Extensibility, Modifiability, Scalability, Versatility,	Accessibility, Controllability, Modularity, Interoperability, Simplicity, Independence, Interoperability, Integrability, Protectability, Readability, Decentralization

There are lots papers that study words and phrases that address these changes, fluctuations, or uncertainties especially about their scope and limitations. To identify change-related ilities this article used keywords on the left side of Table 1 to collect subsequent articles on this subject. For searching the articles Scopus and Google scholar are used together to maximize the results. No limitation was imposed on document type or time span in the searches. Excel was used to track the searches and archive them. Various combination of mentioned keywords has been used in a logical order. The whole work was iterative and new words and phrases were constantly added to the excel sheet to increase the depth of searches. As for our procedure, First, articles were filtered by their title and the results gave us the first round of articles to work with. Second, the selected articles' abstracts were read, and they were filtered based on relation to the topic by asking three major criterion questions used to limit the papers as below.

- Is it related to change related system properties (ilities)?
- Is it giving a definition for ilities or try to compare them (have a semantic view)?
- What domain does the paper belong to (product or production)?

Many articles (roughly 80%) were found to be using the mentioned terms as the desired effect on their system. This means their focus was more on studying the method or mechanism and achieving these attributes without giving any definition on them. For example, a lot of articles employ tactics to get one ility as an attribute in their system. Yet for the purpose of the current paper, which is to hold on to the system engineering approach, these articles were not looked through.

Focusing on product development, some articles with the ontological view in production or manufacturing were also not included in the source papers. The reason for this is that changeability may have different semantic fields between product and production discipline and this difference falls out of the scope of this paper. However, for understanding the difference between the meaning of change-related ilities in product and production domains readers are directed to the article [16] and [17]. Nevertheless, some articles that have broader scope about systems in generic form and literature address them as system engineering papers. They are included in the search results considering that they satisfy other criterion questions.

2. Recognizing system properties in change propagation

As mentioned, in today's everchanging markets and dynamic environment, the key to success for companies is to be able to address late decisions or unanticipated problems and incorporate changes into their offerings even after its release into the market. Clark et al [18] stated that "Late implementation of a change from one phase to another phase (e.g., concept, manufacturing, operations) becomes 10 times more costly". They described this as the "Rule of Ten". Wildemann in 1994 was first to suggest three tactics to manage changes in the systems and Fricke et al completed it by adding two more tactics [13]. To name them, Prevention, Front loading, Effectiveness, Efficiency, and Learning. Later, [19] proposed the design for changeability. Their aim was to make a system more open to changes during its life cycle in dynamic markets. Figure 1 is the adoption of this concept. Flexibility is accomplished when the system can change through its life cycle easily and without facing failure. This is a prerequisite for being agile, which needs a system to be able to change rapidly [19].

To understand this better, consider a modular die, it may be easy to change a module, but it could be time-consuming as it may need a production line to be shut down, and perhaps it takes a lot of time to restart it. Though, in an agile system, a die should be able to quickly be updated on the production line even if it requires not easy-to-use tools to do this task. In the same way, robustness is accomplished when the system is incentive toward its environment, and it is a prerequisite for being adaptable which is when the system can be used under different conditions. For example, a component's tolerances in the assembly line could be robust toward small manufacturing deficiencies and still be assembled. Yet, we can say it is adaptable when this component is able to be used for a totally different product than the one it is initially developed for. This is a particularly useful attribute in product platforms when we cannot foresee the future variants of a product family. Lacking any of these attributes, in a system like product realization, can cause failure directly or indirectly by propagation of change to other phases.

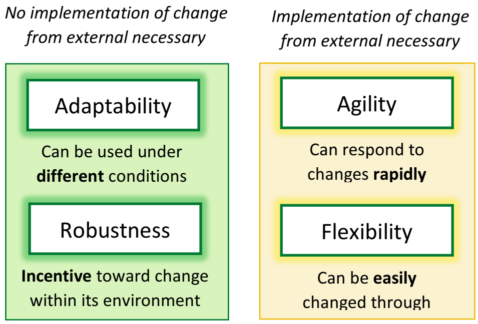


Figure 1. Various aspects of changeability

Ross et al. [14] also made an attempt to define changeability in terms of several system characteristics, namely, Robustness, Flexibility, Adaptability, Scalability, and Modifiability. In this way, first, they presented an enhanced definition of *change* in terms of the transition from one state to another. This definition characterizes a change based on three elements: *agent* of a change, *mechanism*, and its *effect*. These elements are shown in Figure 2 (a). The change is represented by a path from one state to another and changeability is defined as how easy a system could complete this path. *The agent* is a force that drives the change and it could be triggered supervised, like a decision (e.g. mechanical mechanism, software, etc.) or unsupervised like a natural force (e.g. Gravity, wind, etc.). The agent's location is another attribute that is most useful in making a distinction between flexibility and adaptability, if it is an internal agent, the system could be named as adaptable. If the agent is external to the system, the system is called flexible [20]. This concept is also depicted in Figure 2 (b). In this definition, the distinction between flexibility and adaptability also depends on the type of change. System boundary plays an important role in removing the ambiguity in this distinction. The change *effect* is another element that is defined as the difference between the initial and late state of the system. This element helps to make distinction between modifiability, scalability, and robustness.

To illustrate better, consider a system that has three parameters: a, b, and c. And each of these parameters could have three values, which are labeled sets. a = $[a_1, a_2, a_3]$ and b = $[b_1, b_2, b_3]$ and c = $[c_1, c_2, c_3]$. In this way, system X could be defined as $X = (a_1, b_2, c_3)$. Suppose designers change the environment that this system is currently working. If X maintains its performance, then we call it a robust system. If designers change one of the parameters of the X so it is equal as $X = (a_1, b_2, c_2)$ and the system runs without any performance loss then we call this system scalable. Finally, if the designer introduces a new set, as d, and changes the system's parameters to be $X = (a_1, b_2, c_4, d)$ and still the system is functioning then the system is modifiable. These characteristics are shown in Figure 2 (c). The last element is the change *mechanism* which is defined with the path that is used by the system to get to a later state. Depending on the mechanism, system cost and revenue may change. Figure 2 (c) shows 4 different change mechanisms with different costs between the same initial and later states.

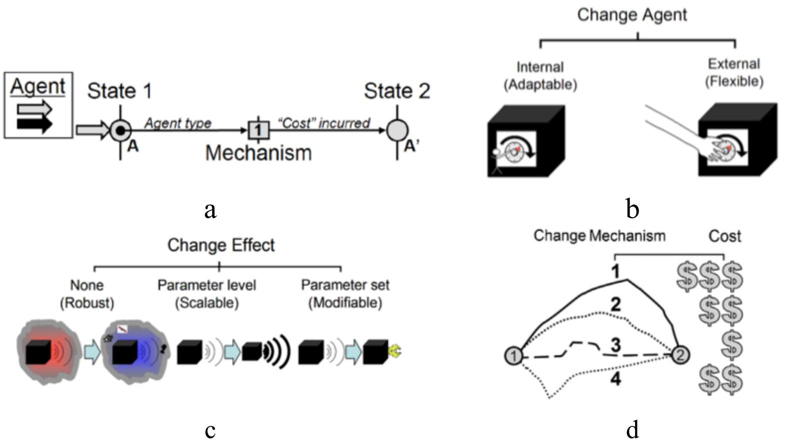


Figure 2. Changeability elements and distinction they make between ilities [14].

De Weck, et al. in the article [21] investigated relationships and semantic sets amongst system lifecycle properties, and they basically give the same definitions and classifications as presented by [14]. Yet in their book which has published one year ahead [22] they devoted a chapter on defining life cycle properties of engineering systems and presented some other definitions. Other students from MIT system engineering advance research initiatives that have published definitions in this area have identical definitions such as [23] and [24].

Uncertainties are defined by [25] as "the inability to determine the true state of affairs of a system" or "things that are unknown or known only imprecisely" by [26]. These undesirable effects are sometimes the reason behind a late decision or change in the systems that end up propagating in the systems or more specifically in the product realization realm. Some authors acknowledge this fact by focusing on characteristics that can make a system incentive toward uncertainties [27]. They compare several system characteristics (ilities) that act as a protection against uncertainties and attempts to mitigate them without removing their source. The paper [27] employs several perspectives on reliability. And based on these three viewpoints the article defines reliability as *the ability of a system to perform as expected in a stable environment.* In this way, reliability is used as an umbrella concept for several other characteristics. Robustness is defined as the ability of a system, as-built/designed, to do its basic job in uncertain or changing environments. This attribute is considered passive, meaning it is designed to ensure its capabilities and to withstand the uncertainties. Adaptability is defined as the ability of a system to be modified in order to do its basic job in uncertain or changing environments, changing requirements are omitted from this definition. Adaptability is considered active with variable structure meaning the system changes itself to adapt to the new environment. For example, some of the high-tech car spoilers adjust their height to compensate for the vehicle's aerodynamic shape at varying speeds. In Robustness the change is intrinsic, and the protection is passive. This difference is illustrated in Table 2 for different system properties [27]. *Versatility is defined as the ability of a system, as-built/designed, to do jobs not originally included in its requirements.* And resilience in a narrow sense focuses on a system's recovery from perturbation. *Flexibility is defined as the ability of a system to be modified to do its basic job or jobs not originally included in the definition of the system's requirements in uncertain or changing environments.* Flexibility considered active protection and also it was argued that it could work as a facilitator for robustness.

Table 2. classification of conceptual approaches to system protection against uncertainty.

Concept	Variable Requirement	Variable Structure	Variable Environment	Active considered	Source of Uncertainty
Reliability					System
Robustness			√		System + Environment
Adaptability		√	√	√	System + Environment
Versatility	√				System + Requirement
Resilience	√		√		System + Environment+ Requirement
Flexibility	√	√	√	√	System + Environment+ Requirement

In another research [28] has introduced an ontological framework to clarify different aspects of flexibility, adaptability, robustness. They prepared three different tables, each for one of the attributes, namely, flexibility, robustness, and adaptability. Based on the proposed framework the authors attempted to suggest a more clarifying definition on mentioned ilities. Flexibility was summed up as the measure of how easily a system's capabilities can be modified in response to external change. Adaptability was concluded to be the measure of how effectively a system can modify its own capabilities in response to change after it has been fielded. Finally, robustness regarded as the measure of how effectively a system can maintain a given set of capabilities in response to external changes after it has been fielded. In this sense, a robust system handles the change in the environment without really changing itself.

3. Comparison and analysis

As discussed in the previous section, some of the system properties (ilities) can be defined in association with addressing the changes and butterfly effects. Studying the change in generic form enables a transdisciplinary approach that can fit well in various disciplines of product realization. Whether it is a comprehensive manufacturing system or a system for the detailed design, it can still fit in discussed definitions. Therefore, running a system-level research clarification phase at the beginning of the this research project was essential. Table 3 summarizes the results with the aim of giving a brief overview and a comparison between ontological studies at hand.

The citation of each article was also brought in the table2 and it is basically an indication of the impact of the proposed definition. As can be seen, Flexibility, Adaptability, and Robustness are the most repeated system properties between different papers in the product domain. For the production domain, Flexibility and Reconfigurability are the most repeated ones. The difference between the two domains

[2] Pulled out at 30 January 2020 at the time of writing this article.

shows that changes can mean different things in two domains. For transdisciplinary nature of the Butterfly Effect project, meaning that it aims to study change propagations between several disciplines, this is very important. Repetition of ilities used in defining changeability in each author is also important since it shows unanimous definition and agreement of authors for defining and classifying these terms. There are some other attempts like [30] and [31] to classify these definitions in different structures but since they don't give any definition of their own, their articles are not included in this table. Also, a problem with their approach is that it is hard to compare different views on various definitions.

Table 3. Different ilities each author used for their definition.

Domain	Article	Times Cited	Used ilities
Product	Fricke and Schulz [19]	417	Changeability (Flexibility, Adaptability, Agility, Robustness)
	Ross, et al. [14]	351	Changeability (Robustness, Modifiability, Scalability) also Changeability (Flexibility, Adaptability)
	DeWeck, et al. [22]	279	Flexibility, Adaptability, Agility, Evolvability, Reconfigurability, Scalability, Extensibility
	Chalupnik, et al. [27]	49	Reliability (Flexibility, Adaptability, Robustness, Versatility, Resilience)
	Ryan, et al. [28]	65	(Flexibility, Adaptability, Robustness), and Agility, Changeability, Versatility
Production	Wiendahl, et al. [16]	964	Changeability (Changeover-ability, Reconfigurability, Flexibility, Transformability, Agility)
	Terkaj, et al. [29]	73	Flexibility (Flexibility, Reconfigurability, Changeability) also (Range, Resolution, Mobility, Uniformity)
	Benkamoun [17]	6	Changeability [Flexibility (Built-in, Changeover-ability), Reconfigurability (convertibility, extensibility)]

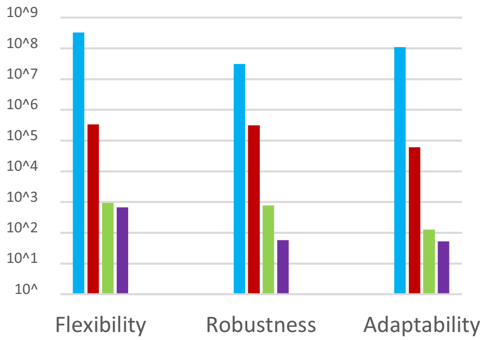
To avoid disperse definitions in several tables and better illustrate and compare definitions given by each author on the mentioned terms, Table 4 is put together in this study. This Table summarizes papers in the product domain with a gist of each term's definition. The numbers in the table refer to the definitions listed beside the table. For example, Fricke and Schulz for Flexibility used definitions 1 and 7 (or at least these numbered definitions are aligned with the author's discussion). An interesting inference is that the definition for adaptability and robustness is almost unanimous by different authors but there is no consensus about the definition of flexibility. For example, the definition "Maintaining capabilities in changing environment" is more or less repeated by many authors for robustness and the same is true for the definition of "System can change itself actively in response to varying condition" for adaptability. One can conclude that the authors in system engineering believe adaptability to be the intrinsic ability of a system to change itself and adapt to changes. As for the robustness, the agreed-upon definition is the ability to maintain its capabilities in a changing environment. It is only Ross, et al. [14] that doesn't approve this definition for adaptability.

However, for flexibility, different authors give different definitions and no unanimity can be seen between them. Interestingly, flexibility is the only attribute that is repeated and shared between the product and the production domain (base on table 3). It cannot be determined if this is the reason for such variations in the definition of flexibility. Nevertheless, ambiguity in this filed can be troublesome for scholars and damage the development of the field. To fully understand the trend in literature and the Internet about these three ilities (Flexibility, Adaptability, and Robustness), a comparison was made which is brought in Figure 3. This comparison was previously done in 2011 by De Weck et al. [22] and we used their data to find out what has changed in this last decade.

Table 4. Definitions that different authors used and their overlap.

Domain	Article	Flexibility	Adaptability	Robustness
Product	Fricke and Schulz [19]	1,7	2,8	3,8
	Ross, et al. [14]	4	5	-
	DeWeck, et al. [22]	6,1	2,4	3,9
	Chalupnik, et al. [27]	10	2	3
	Ryan, et al. [28]	1,4	2	3,4

1- Being able to change easily (effort) in a passive way
2- The system can change itself actively in response to the varying condition
3- Maintaining capabilities in changing environment
4- Force instigator (agent) for the change is external to the system
5- Change in response to an internal agent
6- Umbrella term for several other ilities
7- Changes from external must be implemented to cope with changing environments.
8- No implementation of change from external is necessary
9- Sub-ility for the Resilience umbrella
10- Ability to be modified to do jobs not originally intended by the original design



	Increase (%)
Flexibility on Google	287
Robustness on Google	259
Adaptability on Google	383
Flexibility on Scopus	195
Robustness on Scopus	312
Adaptability on Scopus	278

Figure 3: Trend in three different system properties over the past decade.

In this figure, numbers from [22] are compared to numbers that were extracted by this paper. What is interesting is the amount of increase in these numbers. For example, the bars over robustness, shows that the number of articles increased 312% in Scopus (purple bar to red) from 2011 to 2020. Yet this increase for flexibility in Scopus is 195%, which is very low comparing to robustness growth. The fact robustness in Scopus has experienced more increase in comparison to flexibility, shows although flexibility was well published in previous years, Robustness is getting much more attention nowadays from scholars. This is interesting from the Butterfly Effect research project's point of view to know which system properties are trending in academic literature. Another interesting fact is adaptability hits on Google which has been increased by 383% from 2011 to 2020, still, this increase is Scopus is 278%. This also shows that adaptability is not getting the recognition it used to get from scholars and academic society. Overall, one can predict that robustness as a system property is on the verge of outburst and we can expect to see more papers on this system property in the years to come. This also helps us to focus more on Robustness in future works as a trend in literature.

4. Conclusion

Changes are inevitable through every phase of product realization. They may cause a problem for the system or just lead to the other changes, propagating through different phases of product realization. Most used change-related ilities are extracted as Flexibility, Adaptability, and Robustness. A consensus definition was identified for each of these terms. The performed historical comparison shows that robustness is getting more and more recognition from scholars and it is indeed a trend in the future literature. Results show that three mentioned system properties can be used to address the change propagation in the field of product realization. The next step in the Butterfly Effect research project will be to look at each of these ilities individually to see what supports have been developed to address each of them. The final goal is to develop sophisticated support for change propagations. We will also run interviews with the companies to find case studies to evaluate our proposed support.

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Impact Assessment of Food Safety News Using Stacking Ensemble Learning

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Abstract. Food safety has always been the focus of public concern. Assessment of the impact of food safety news constituents an important job of the government departments. In this paper we present a method using stacking ensemble learning to assess the impact level of global food safety news. The news used for training the assessment model is collected from the Chinese customs. Each of the news articles is annotated with a label ranging from low impact, medium impact and high impact by the customs officials. For base learners in the ensemble learning model, we use Naive Bayesian, Support Vector Machine, XGBoost, FastText, Convolutional Neural Network, LSTM and BERT. A Naive Bayesian-based meta learner is used to integrate the assessment results of the base learners. The proposed method features end to end prediction of news impact using the original news text as input, and it advances the transdisciplinary development of artificial intelligence and risk assessment by improving the accuracy of impact assessment of food safety news compared with traditionally used methods.

Keywords. Stacking ensemble learning, impact assessment, food safety news

Introduction

Food safety concerns the health of people and therefore keeps receiving a lot of attentions from both the public and the government. To monitor the news reporting food safety events and assess the impact of the news constitute one of the important work of the government. With the fast development of artificial intelligence (AI) , the automatic assessment of food safety news using AI techniques such as natural language processing and machine learning becomes realistic and is desired by regulators of the government to improve supervision efficiency. Since food safety news is usually related with adverse events such as food disqualification or detection of harmful substances in food, the assessment of food safety news is similar with assessing the food risks described in the news. In this sense, automatic food safety news assessment becomes a transdisciplinary engineering problem incorporating AI and risk assessment. For risk assessment, it usually comprises recognizing the consequences of adverse events, assessing the probability and severity of each consequence, and synthesizing

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the assessed consequences to get the final result [1]. For example, Fu et al. [2] modeled a risk scenario as an event tree, and then carried out dependency analysis of the associated intermediate events to quantify the probability of event occurrence. Using a quantitative risk assessment method called the Fine Kinney method, Kokangul et al. [3] computed risk as the likelihood of hazardous event multiplies the exposure factor multiplies the possible consequence. This kind of risk assessment makes the assessment process highly depended on expert knowledge and formal representation of risk indexes, therefore lacking the ability to react swiftly to the varying risk situations in the big data era. Recently, there is a trend of assessing risks with textual materials as input [4,5]. For example, Su and Chen [4] assessed the risk in global suppler selection using information mined from Twitter. Duy et al. [5] predicted mental health risk through automated analysis of case notes in electronic health records. For food safety news, it consists of unstructured text with various themes which is difficult to be represented formally. If a model were to assess the impact of food safety news using explicit indexes such as food type, harmful ingredient and region of influence, then a series of dictionaries and corresponding information extractors should be developed, and the assessment result would be affected by the incompleteness of each dictionary and imprecision of each information extractor. In this paper, we propose to assess news impact in an end to end fashion, which is to use an ensemble machine learning model to learn the mapping of news articles to impact grades directly. Such a fashion is similar to the real news assessment process in the Chinese customs, where customs officials grade the impact of a news article immediately after reading it based on their experience. To learn the complex relationship between news articles and impact grades, we first train seven different base classifiers to classify news articles into three categories: low impact, medium impact and high impact. Then a meta classifier is trained with the output of base classifiers to generate the final prediction of impact level. The base classifiers are Naive Bayesian, Support Vector Machine (SVM), XGBoost, FastText, Convolutional Neural Network (CNN), LSTM and BERT. Naive Bayesian is used as the meta classifier.

1. News impact assessment as a text classification task

As a daily routine, the Chinese customs collects food safety news around the world and rated it with three categories: low impact news, medium impact news and high impact news. For low impact news, it is relevant to food import/export but poses little risk for China. News with medium impact may involve announcement of disqualified food, food recall or change of import/export regulations. High impact news is usually related with detection of harmful substances in popularly used imported food, or rejection/detention of Chinese food by other countries. However, the categorization of food safety news cannot be simply done by following the above rules of thumb. This is because the types of food safety news are not restricted to the abovementioned ones and for each type of news, the impact level of the news may vary according to the involved food types, affected countries/areas, consequence of event, economic/political issues and so on. Considering these complex features of food safety news, we believe that a more efficient way for news assessment would be to directly classify a news article in to low, medium and high impact classes using word-based features. Using word-based features enables us to draw upon the latest techniques in text classification and at the same time avoid extraction of complex features which leads to poor reliability and scalability.

Text classification is an intensively studied research field. According to a recent survey, frequently used text classification techniques include Naive Bayesian, SVM, XGBoost, FastText, CNN and RNN (Recurrent Neural Network) [6]. Text classifiers can benefit from proper quantification of text strings. For example, using TF-IDF scores as the weights of words can help a classifier to discriminate between informative words and uninformative words. Word embedding is a technique of representing words with short and dense vectors (compared with one-hot representation of words which is long and sparse) to reflect the semantic meaning of words and improve computational efficiency [7]. Word2Vec, a widely used word embedding method, maps high dimensional one-hot representation of words to a low dimensional vector space by training a neural network [8]. In this paper, we use TF-IDF as the word weights for text classifiers using bag-of-words as input, and use Word2Vec to generate word vectors for neural network-based classifiers.

2. Ensemble machine learning

Although various machine learning methods exist for text classification, it is hard to determine in advance which method performs the best for the given situation. To solve this problem, researchers proposed ensemble learning, a framework of integrating multiple machine learning models. In the context of this paper, ensemble learning is to integrate multiple text classifiers. The text classifiers to be integrated are called the base classifiers, which can be of different types, or of the same type but trained differently. By summarizing the results of the base classifiers, the overall classification result can be obtained, and the accuracy and generalization ability of the ensemble classifier can be improved [9]. Figure 1 shows the framework of the ensemble classifier proposed in this paper.

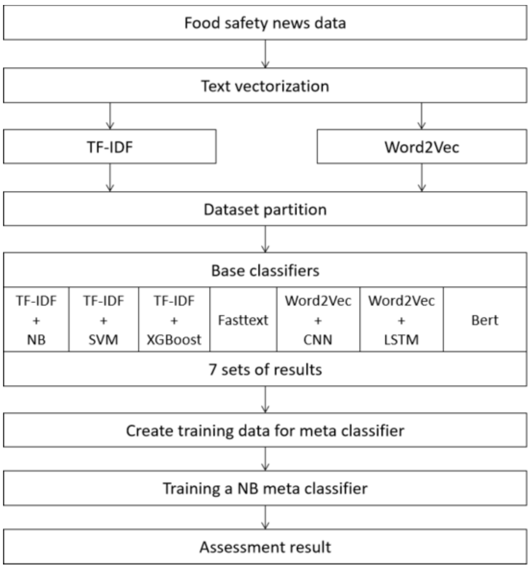

Figure 1. Ensemble classifier for news impact assessment.

2.1. Base classifier

In this research, we use the following classifiers as the base classifiers.

1. Naive Bayesian

Naive Bayesian (NB) is a probability-based machine learning algorithm. Its principle lies in Bayes theorem and the conditional independence assumption of features. When doing classification, NB calculates the probability of each feature corresponding to each class and then obtains the probability of a sample belonging to a certain class. For food safety news, the features are the TF-IDF weighted words in the vocabulary containing all the words in relevant news. Since NB is a widely used algorithm, many machine learning software packages have built-in implementation of it. In this paper we use the SKLEARN package to carry out the training and predicting with NB.

2. SVM

SVM is a classifier looking for the optimal hyperplane in the sample space such that the distance between the hyperplane and the support vectors is as large as possible, so as to ensure the accuracy of classification. SVM is usually used for binary classification. For classes more than two, such as the situation in this paper, a one-versus-rest way can be used to construct the SVM classifier. This way treats one class of the total n classes as a class, and the other n-1 classes as another class to separate the two. So totally n SVM classifiers will be constructed for an n-class classification problem.

3. XGBoost

XGBoost itself is an ensemble learner integrating multiple CART (Classification and Regression Tree) models based on the boosting mechanism. The training process of XGBoost is to create a series of CART trees and grow the trees by splitting the leaves representing decision variables. Each tree learns not to give the final decision but to fit the prediction error of a previous tree, and the final decision can be made by combining the predictions of all the trees. XGBoost applies regularization to the objective function to reduce the total number of tree leaves and the output scale of the leaves, so that overfitting can be avoided.

4. FastText

FastText is a simple three-layer neural network, including the input layer, hidden layer and output layer [10]. At the input layer, n-grams in the training text undergo a bucket hashing process and become the embedding vectors. This enables FastText to utilize the word order in n-grams and at the same time control the total number of n-grams. At the output layer, FastText uses a hierarchical softmax technique based on Huffman encoding, which reduces the number of classes to be predicted and thus improves classification efficiency. Since FastText itself has the ability to generate text vectors, we do not apply Word2Vec to the FastText classifier.

5. CNN

CNN is usually used for image classification. Yoon Kim proposed a variant of CNN, namely textCNN, for text classification [11]. In this paper, we use the word vectors generated by Word2Vec to replace the random word embedding used in textCNN, so as to incorporate more prior knowledge in the classification model. In textCNN, a passage is represented as a matrix whose rows are the embedding vectors of words in the passage, and convolution kernels are of the same length as the embedding vectors. To keep the integrity of word information, the convolution kernels are only allowed to move along the height direction. The convolution layer is followed by a k-max pooling layer. A fully connected softmax layer is used as the output layer.

6. LSTM

LSTM is a type of RNN. LSTM adds an input gate, a forgetting gate, an output gate and a memory unit to a RNN neuron, making the modified model capable of memorizing important information and forgetting unimportant information in a time series [12]. LSTM is very useful for modeling text as the word sequences in text represents time series signals. In this paper, a news article is transformed into a vector sequence and fed to the LSTM classifier. Each vector in the sequence represents the word in the corresponding position and such vectors are obtained from Word2Vec.

7. BERT

BERT [13] and its improvements [14] represent the state-of-the-art techniques in natural language processing. BERT is based on Transformer [15], an encoder-decoder architecture built on multi-head self-attention mechanism. BERT is structured as a multi-layer bidirectional Transformer encoder and is deliberately pre-trained with two types of tasks: masked language model and next sentence prediction. To use BERT for text classification, we directly input news text to the first layer of the BERT model per-trained with Chinese corpus. BERT will generate a vectorial representation of the text using the positional information of words and the knowledge it gained during the pre-training phase. A fully connected softmax layer is used to classify the generated text vectors, and training (often called fine-tuning) the BERT classifier is to learn the weight matrix of the softmax layer.

BERT is a heavy model such that the pre-training and fine-tuning of it require a lot of resources. To use BERT with limited computing resources, a practical way is to constrain the length of input. In this paper, we define 128 Chinese characters as the max length of input news for BERT. To keep as much information in the original news as possible, we apply automatic summarization to the news articles. The method of automatic summarization is TextRank [16].

2.2. Stacking

Stacking is a way to integrate the classification ability of the base classifiers. It uses the class labels (or class probabilities) output by the base classifiers and the real class label of a training sample to form a new training sample. With the newly formed training samples, a meta-classifier is trained to give the final prediction of the class label of an input sample. To prevent overfitting, the training data are divided into 7 sets of equal size shown as $a_1,\ldots, a_7$ in Figure 2. For each base classifier, it is trained 7 times. In the first time a_1 is used as the inner test set and the rest sets are used as the training set, in the second time a_2 is used as the inner test set and the rest sets are used as the training set, and so on. The predicted class labels for inner test set a_i by base classifier j is denoted as b_{ij}. By merging $b_{i1},\ldots, b_{i7}$ along the same test samples, we get B_i, and $B_1,\ldots, B_7$ comprise the training set for the meta-classifier. Since each base classifiers have 7 differently trained versions, but when testing the ensemble classifier, the meta-classifier needs a determined class label from each base classifier, we test the seven versions of the base classifier with the overall test set one by one, and choose the most frequently appeared class label for each test sample. In this fashion we get T_i, the test result of base classifier i, and by merging $T_1, \ldots, T_7$, we get T, the test set for the meta-classifier.

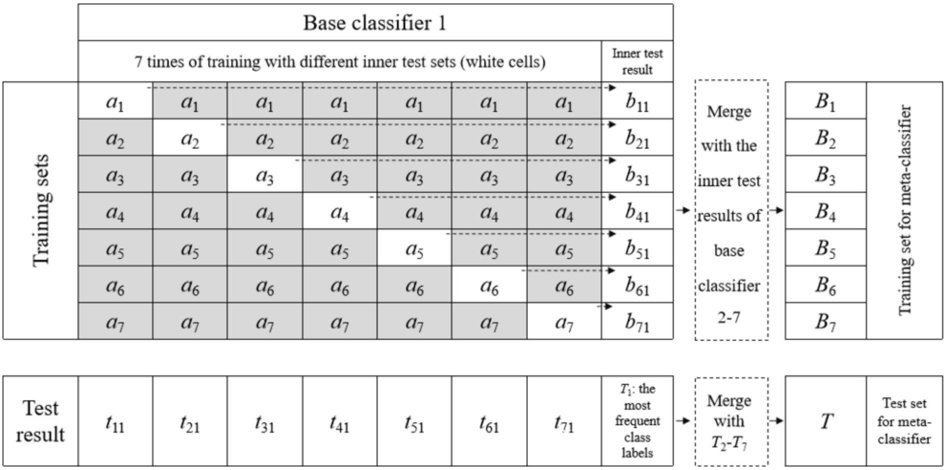

Figure 2. Construction of training and test datasets.

3. Experiments

3.1. Data acquisition and preprocessing

The food safety news used for impact assessment experiment is acquired from the Chinese customs. Totally 21,065 news articles were collected each with a class label ranging from low impact, medium impact and high impact. The labels were assigned to the news articles by the customs officials manually. There were 10,247 low impact news articles, 10,314 medium impact news articles and 504 high impact news articles. From each kind of the news articles, a 25% fraction is randomly chosen to constitute the test set, and the rest 75% constitutes the training set. All the news articles were in Chinese because all the news written in other languages were translated by the customer officials into Chinese. After using the jieba software to segment the Chinese news, we got 88,296 distinct Chinese words, based on which the TF-IDF weights of words were calculated. The dimension of the output vector of Word2Vec (the genism version) was set to be 50.

3.2. Settings of base classifiers

Each base classifier has some hyper-parameters that control its training and predicting process. In this paper, the hyper-parameters of the base classifiers are set as Table 1.

Table 1. Hyper-parameters for base classifiers.

Base classifier	Hyper-parameters
NB	Uniform prior probabilities of classes; other parameters follow the default setting of sklearn MultinomialNB model.
SVM	Parameters follow the default setting of sklearn LinearSVC model.
XGBoost	Early stopping rounds = 10; eval_metric = "logloss"; other parameters follow the default setting of Python package xgboost.
FastText	Minimal number of word occurences = 2; other parameters follow the default setting of Python package fasttext.
CNN	Keras-based implementation of a textCNN [11]-like CNN, with a dropout layer after the embedding layer (dropout rate = 0.2); the 1D convolutional layer has 250 filters (kernal length = 3); a 3-max pooling layer follows and is followed by a flatten layer, a 50-unit dense layer and a 3-unit softmax layer; the activation function of the convolutional layer and the dense layer is ReLU; input length = 1000, batch size = 256, epochs = 5.
LSTM	Keras-based implementation of LSTM; the embedding layer is connected to a LSTM layer with 200 neurons, where a 0.2 dropout rate of the input and recurrent state is applied; following the LSTM layer is a dropout layer (dropout rate = 0.2), a 64-unit dense layer (ReLU activation function) and a 3-unit softmax layer; input length = 1000, batch size = 128, epochs = 5, Adam optimizer, learning rate = 0.01.
BERT	Chinese pre-trained model, L=12, H=768, A=12; batch size = 32, epochs = 5, learning rate = 2e-5; input length =128, input text is summarized using the "TextRank for sentence extraction" method proposed in [16].

3.3. Experiment result

We use accuracy, precision, recall and F1 score to evaluate the performance of news impact level assessment. These indexes are established based on the following concepts:

- True positive (TP) - predicted to be positive and true label is positive
- False positive (FP) - predicted to be positive but true label is negative
- True negative (TN) - predicted to be negative and true label is negative
- False negative (FN) - predicted to be negative but true label is positive

Then the abovementioned performance indexes are calculated as:

Accuracy = (TP+TN) / (TP+TN+FP+FN)
Precision = TP / (TP+FP)
Recall = TP / (TP+FN)
F1 = 2 * Precision * Recall / (Precision + Recall)

For n classes where $n > 2$, each class is chosen for calculating its own TP, FP, TN and FN, during which phase all the other classes are treated as the negative class. Then the TP, FP, TN and FN for each class is added respectively for computing the overall accuracy, precision, recall and F1 score. In this way we get the final performance of the proposed ensemble classifier, which is accuracy = 0.8062, precision = 0.8071, recall = 0.8062 and F1 = 0.8052. Figure 3 shows the confusion matrix of the ensemble classifier, where label 0, 1, 2 correspond to low impact, medium impact and high impact class respectively.

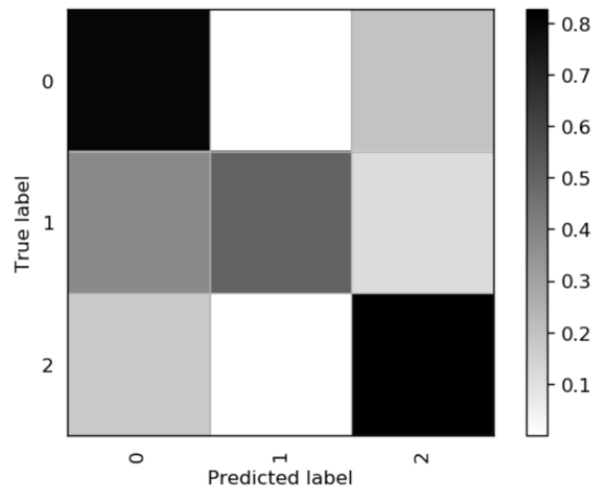

Figure 3. Normalized confusion matrix of news impact level prediction.

4. Comparative study

We carried out comparative experiments to verify the advantage of the proposed method versus existing methods. We first compared the ensemble classifier with the seven base classifiers, and then compared it with four classic classifiers, saying, the original version of NB, SVM, CNN and LSTM without using TF-IDF weights or pre-trained word vectors. The result of the comparison is shown in Table 2.

Table 2. Results of different classifiers.

Model/Index			Accuracy	Precision	Recall	F1
Classic	NB	One-hot	0.7312	0.7652	0.7312	0.7321
	SVM	One-hot	0.7532	0.7563	0.7532	0.7535
	CNN	Random embedding	0.7782	0.7882	0.7782	0.7806
	LSTM	Random embedding	0.7845	0.7852	0.7845	0.7848
Base classifier	NB	TF-IDF	0.7587	0.7615	0.7587	0.7592
	SVM	TF-IDF	0.7968	0.7990	0.7968	0.7972
	XGBoost	TF-IDF	0.7902	0.7918	0.7902	0.7905
	FastText	-	0.8027	0.8037	0.8027	0.8030
	CNN	Word2Vec	0.7870	0.7907	0.7870	0.7879
	LSTM	Word2Vec	0.8018	0.8064	0.8018	0.8024
	BERT	Auto summarization	0.7919	0.7934	0.7919	0.7921
Ensemble classifier		TF-IDF + Word2Vec	0.8062	0.8071	0.8062	0.8052

From the results in Table 2 we can see that the proposed ensemble classifier achieves the highest scores regarding all the performance indexes. The second runner is FastText, which scores 0.35% lower than the ensemble learner in terms of accuracy. LSTM with Word2Vec embedding performs similarly with FastText, but the version of LSTM with random embedding performs much poorer. By comparing NB, SVM, CNN and LSTM between their classic versions and base classifier versions, it can be seen that using information and knowledge extracted from the corpus can improve the performance of the classifiers. For BERT, which uses the most prior knowledge and represents the state-of-the-art of natural language understanding, it scores below the ensemble classifier, FastText, LSTM(base classifier version) and SVM(base classifier version), but scores above all the other classifiers. This is probably due to the shortened input of BERT.

5. Conclusion

In this paper we propose a news impact assessment method based on ensemble learning. The ensemble learner integrates NB, SVM, XGBoost, FastText, CNN, LSTM and BERT-based classifiers to classify food safety news into the low impact, medium impact and high impact categories. With word weights and word vectors learned from the corpus of news articles, the performances of the base classifiers are improved and the final ensemble learner achieves higher accuracy than many classic machine learning models. The proposed method realizes end to end assessment of news impact and can be used in the Chinese customs to improve the efficiency of food safety news assessment. It promotes the transdisciplinary research in artificial intelligence and risk management in the importation field. We also discovers that if the user is willing to sacrifice a little accuracy, then the FastText classifier can be used to predict the impact level of news, which requires a much smaller set of resources.

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Automated Generation of a Digital Twin of a Manufacturing System by Using Scan and Convolutional Neural Networks

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Abstract. The simulation of production processes using a Digital Twin is a promising means for prospective planning, analysis of existing systems or process-parallel monitoring. However, many companies, especially small and medium-sized enterprises, do not apply the technology, because the generation of a Digital Twin is cost-, time- and resource-intensive and IT expertise is required. This obstacle can be removed by a novel approach to generate a Digital Twin using fast scans of the shop floor and subsequent object recognition in the point cloud. We describe how parameters and data should be acquired in order to generate a Digital Twin automatically. An overview of the entire process chain is given. A particular attention is given to the automatic object recognition and its integration into Digital Twin.

Keywords. Digital Twin, Digital Factory, Object Recognition, Indoor Object Acquisition, Simulation

Introduction

The Digital Factory has already been recognised as a strategically competitive advantage by the industry and is closely linked to the company's overall business strategy, that can be implemented throughout the organization. The results of a survey show that 91percent of industrial companies are investing in digital factories and only six percent of respondents describe their factories as being fully digitized yet [1]. Many fields of application exist today for digital models of a production system in a discrete event simulation (DES), e. g. planning of factories, layout optimization in the shop floor, approval processes in the area of reconstruction and fire protection, or optimization of production processes. Simulation in particular is a core element of the digital factory and is becoming increasingly important as a result of developments in the area of digitisation [2]. Nevertheless, current studies prove that the use of simulation models for production systems (hereinafter also referred as "Digital Twin in manufacturing") in small and medium-sized enterprises is still not standard [3]. The main reasons for this are [4][5]:

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Non-transparent procurement costs, required IT expertise (e. g. due to inefficient or overly expensive services), non predictable operating costs (e. g. owing to manual or inefficient adaptation of the Digital Twin), and lack of knowledge regarding available simulation tools and application areas, as well as the achievable benefits.

There are various approaches to overcome the described obstacles. A preliminary report has been presented [6]. Deep product semantic as well as high quality CAD data of all geometrical objects in all stages of planning process are the pre-requisite for seamless downstream processes [7]. With fast scans of the shop floor and subsequent object recognition, the production layout (e. g. size and location of the objects) and the production semantic (e. g. machine types, transport routes) can be recorded as automated as possible and visualized true to scale in digital models [8][9] [10]. The identification of CAD models from a reference library and the transfer of geometry and other object data (e. g. machine types) as modular objects directly from the library significantly reduce the scan times for a first rough "prescan" of the production [11]. At the same time, database reconciliation enables the use of simpler and cheaper scanning methods [12]. The definition of suitable interfaces enables the transfer of information into a program for simulation of production systems and a precisely fitting Digital Twin of the manufacturing can be generated - almost without manual interventions [13][14].

The remainder of this paper is structured as follows: In Section 1 the solution concept and demonstration of the use cases are presented with the related discussion in Section 2. Finally, Section 3 summarizes the conclusions and outlook.

1. Solution concept

1.1. *General approach*

The general approach for an automatic generation of a Digital Twin is given in source [6]. Starting from the existing production system, it consists of three fundamental steps:

1. Scanning the production system to obtain a point cloud (section 1.2),
2. Modelling with the objective of creating a mock-up a as CAD model (section 1.3), and
3. Simulation modelling for the generation of a Digital Twin (section 1.4).

Scanning is conducted by using either high-resolution video camera for prescan standard terrestric scanner (Zoller + Fröhlich, FARO, Leica or similar) or a mobile high-resolution camera. Modeling need to be heavily supported by object recognition to save time, which would be spent in the step of manual remastering. The object parameter (e. g. machine characteristics) are stored in the CAD library and additionally linked with an external database. Scalability is an important requirement for this approach because theoretically each of the infinite built objects need to be recognized. The expert knowledge of the built environment need to be acquired by forms or expert interviews and also inserted in the simulation process. Provision of adequate 3D models and additional specific information of the factory equipment by their manufacturer is standard at this time. Usually, models are delivered in neutral and native formats. For the intended purpose, cooperation with the manufacturers of the machine tools has been established to get appropriate and accurate 3D models. For older objects which does not have 3D documentation, an alternative approach need to be developed to derive a feature-based model, e. g. by recognition of singular features.

1.2. *Scanning the production system to obtain a point cloud*

The scanning of production layouts is largely done with a laser scanner. The single scans are connected with each other via registration. If High Dynamic Range (HDR) images are taken in addition to the laser scan with a standard triggering, a maximum of eight scans can be performed per hour. If the factory is filled with a lot of machines, a large number of single scans are required to avoid the shadowing. During the scan, no further information about specific machines can be included in the 3D point cloud. Alternatively, the shop floor is filmed with a camera and depth image or a stereoscopic camera [9]. It is possible to include information about QR code, language, etc. during the recording in the 3D point cloud. The camera can be mounted on a drone, tripod or held in the hand.

During the scanning process the user is shown the progress via a 3D mesh. The 3D mesh is faded into the filmed image. Due to the color change between scanned and not scanned, the user is able to follow the progress. The 3D mesh is built up based on feature recognition. In the case of structurally weak areas, the user must film more intensively, so thatmore images of the area are saved. The individual images are streamed to a central system via WLAN. The generation of the 3D point cloud is done in the following step. With the offline generation of the 3D point cloud it it is also possible to carry out further optimization over the complete 3D point cloud and thus further increase the accuracy.

It is also planned to integrate mobile phones with a depth image. These mobile phones provide a color and depth image. With this procedure the user is able to scan a layout of the shop floor with a mobile phone at any time. Furthermore, the investment in such mobile phones is manageable at about 800 €. The accuracy is currently around two centimeters and is therefore sufficient for the specifications (Figure 1).

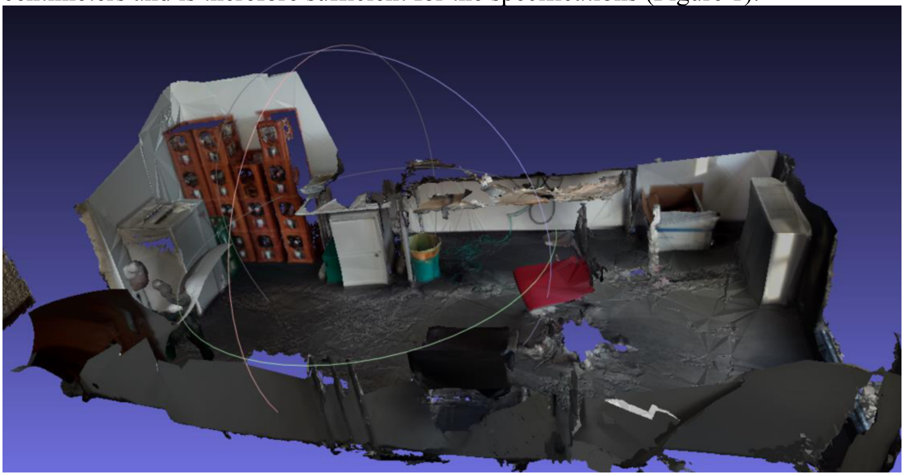

Figure 1. 3D Reconstruction with film.

The further processing through object recognition and the subsequent modelling up to the Digital Twin gains a sufficient basis. However, challenges for the next steps also emerge. For example, the point cloud represents a section that becomes an overall image by combining it with other point clouds. Furthermore, the resulting overall picture is hardly manageable because the amount of data is too large. Accordingly, a meaningful segmentation into separate objects must take place for object recognotion. At this point, the question arises whether the degree of detail of the laser scanning is necessary. In addition, the example shown demonstrates that in production, especially when scanning during production times, occlusions and covers need to be handled.

1.3. *Modelling with the objective of generating a mock-up*

Object recognition based on the point cloud from scanner was taken as a basis procedure for generating a mock-up. The approach is to set up a library with all relevant objects as parametric models and recognize them in any point cloud as often as it occurs. Subsequently, the generation of a mock-up would be reduced to recognition of already known objects and minimal manual rework. For this purpose, an automated object recognition workflow was built up with a modular structure to consider different recognition approaches, based on previous comparison of publicly available frameworks [7][15]. This workflow provides the possibility to embedd different recognition algoritms. Based on previous research [15], three popular algorithms were taken in the shortlist: VoxNet [16], VoxelNet [17] and G3DNet [18].

VoxNet and VoxelNet transform the point cloud into voxels that each contain a small amount of points. It produces bounding boxes based on the features of the voxels. G3DNet, as a point based method, is a DL architecture that is used in 3D object classification and segmentation. It attempts to semantically segment each point in the data by learning the local and global features of the points and classifying each of them. Clusters of points with the same labels can be detected as objects.

A basic amount of relevant objects was selected and transformed from SolidWorks into point cloud using a virtual scanner (Helios). Augmentation of data has been done with 24 rotations (Figure 2). This data set was used for training of a Convolutional Neural Network (CNN). For testing (e. g. object recognition in practical sense) several measures were necessary. The large amount of data (approx. 6 GB for area of 1.000 m^2) causes the data processing to be slow and time-consuming. This would not be acceptable in term of a smooth and fast workflow. Furthermore, each data set must be checked and adjusted manually, because during the scanning procedure undesired reflections, in particular on glass surface, occur, which must be removed as “false data” by using a point cloud editor.

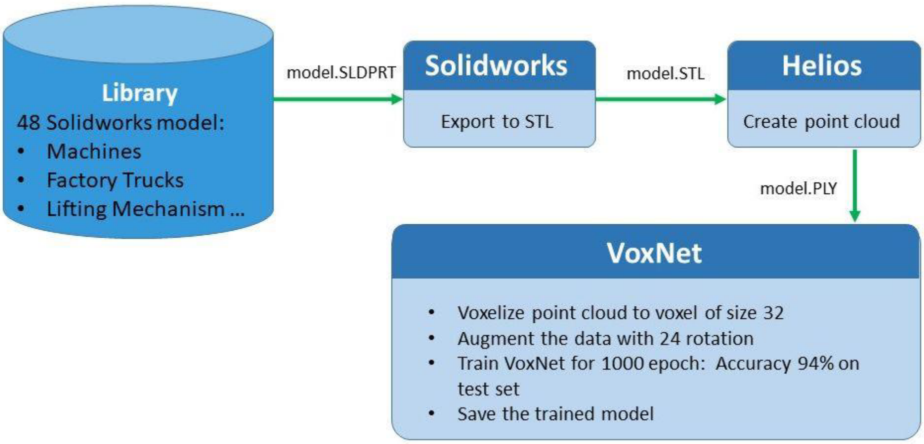

Figure 2. Training procedure, (e.g. based on VoxNet [16]).

Additional methods were developed to simplify object recognition. Although object recognition algoritms are capable to search for objects in each space, for an intended industrial explotation some preprocessing and adjustment in sense of subdivision (segmentation) of huge spaces (and data volumes vice versa) look promising. First issue was a preselection of smaller agglomerations in the entire point cloud which are assumed to contain an object, by using a Point Cloud Library (PCL) module [19]. PCL presents an approach to the subject of 3D perception of point coulds and it is meant to provide support for all the common 3D building blocks that applications require. The library contains state-of-the art algorithms for: filtering, feature estimation, surface reconstruction, registration, model fitting and segmentation. PCL is supported by an international community of robotics and perception researchers. In particular, the functions for filtering and segmentation of a point cloud were applied.

Cluster extraction in the point cloud of a hall proceeds in three steps (Figure 3). At first, the point could is reduced (sparsed) by using a voxel grid filter. Subsequently some unnecessary objects (floor, walls and the roof points) are removed by using the normal segmenter. Finally, all existing clusters in the hall are extracted by using the Euclidean Cluster Extraction. The result of this module consists of different clusters, which then are used for object prediction in order to determinewhich objects contain the corresponding point cluster.

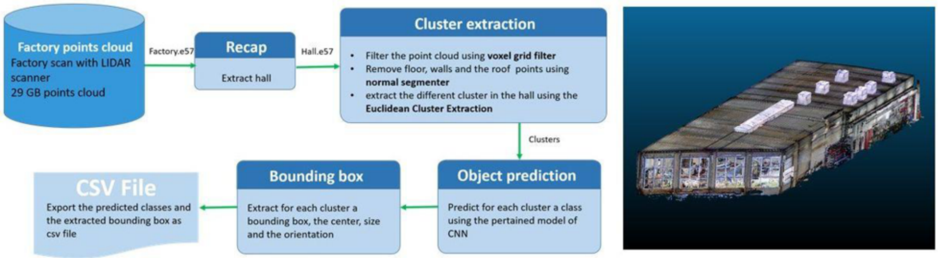

Figure 3. Testing workflow.

To conclude this process chain, two final steps are necessary. At first, for each cluster a bounding box is created to (a) visualize the search space and (b) facilitate the result check and remodeling process, if the recognition is not successful. For an experienced user, it is quite easy to visually check wheter an object is covered by an appropriate bounding box. Furthermore, the bounding box allow a simple check of proper orientation of the recognized object in space. Finally, the collection of clusters, recognized objects and corresponding bounding boxes can be understood as an assembly with singular parts represented either by a model or by a bounding box. Therefore, the framework creates an assembly structure, where singular object are considered as parts of such an assembly. This structure makes the check, modification, repair and extension of such mock-ups much easier [20].

The result of this process chain consists of a CSV file, which works as a steering part, with corresponding objects and bounding boxes as secondary result. Such a structure can easily be imported into, for example, SolidWorks and enhanced with original and parametric SolidWorks parts from the model library. In case of not successful recognition, the user receives a hint for a repair operation. The procedure is repeated until a desired result is achieved. The remaining not properly recognized objects should be processed using the CAD functions of SolidWorks preferrably embedded in macros.

1.4. *Simulation modelling for the generation of a Digital Twin*

In the following the process of simulation modeling is presented in more detail. As mentioned, the representation of the production system generated by the scan and subsequent object recognition is provided as a CAD model. A tree structure is used to arrange and correlate different objects of the production system. The upstream process was therefore designed in such a way that the tree structure distinguishes objects that must also be distinguished for the simulation model, e. g. machines, conveyors or transport equipment.

The export of the model operates as follows: The tree structure of the model is looped through by a macro in SolidWorks. The structure is transferred to an XML file. Since the XML structure can adopt the tree structure of the model, the method mainly adopts the data that is stored in the model and inserts it into the interface [21]. Here, a distinction is made between the input parameters already described, such as machines, conveyors or transport equipment. Every item is assigned attributes. These attributes can be different for various objects, depending on the properties of the objects. For example, processing time can be stored for machines, while for a conveyor belt the length is stored in the XML file. However, it is also possible to store the same attributes for both example objects mentioned. For example, the locations in the model are transferred here in X and Y coordinates. The method then finally generates an XML file that must be saved locally.

Next it is shown how this XML file can be imported into the simulation software and how the model setup is carried out afterwards. The import of the XML file to the simulation software is structured in such a way that all values from the XML file are first written into an internal table of the simulation software. This procedure is useful because it reduces the calculation time. The simulation software gets access to the XML file only once and reads out all data, which leads to a performance advantage. In the program code, this import is therefore autarkic to the model generation. Furthermore, the import is simple, since the structured design of the XML file means that no further adjustments to the data are necessary. For example, the data type, such as string or integer, is transferred and stored accordingly in the simulation software. A further processing of the data is hereby directly feasible. The internal table in the simulation software corresponds to the structure of the XML file, i. e. all attributes correspond to columns and the single objects are listed line by line.

The model construction is carried out by an autarkic method, too. For this, the internal table created by the import is step by step run through. Each line corresponds to an object of the model, so that a simulation module is generated here in each case. In the first step, a case analysis is carried out, which depends on which object type is given. This means that a different generation process is carried out for a machine object type than for a means of conveyor, for example. This corresponds to the differently stored parameters, as mentioned above. In a second step, a part of the model is then generated for each object. For this purpose, the item data is first used to place the object. This data must be scaled to the size of the simulation model surface. Then the specific data is added to the generated module. These differ depending on the type of object. Once the method has been completed, a rudimentary model is obtained. This concludes the automated part of the method. User input is required for further automated generation steps. An additional method has been developed that implements predecessor and successor relationships in the model based on the production schedule. For this the production schedule is required first, which cannot be determined by the scan and the subsequent object recognition. In order to design this process as efficiently as possible, predefined tables have been stored in the model, which can be filled either with minimum effort by experts of the production system or by a defined export, for example from a manufacturing execution system

(MES). By the end of the method or the connected methods after user input, a conditionally operable simulation model is obtained, which can be extended to a Digital Twin. To process the above-mentioned use cases is still missing [22][23]:

- if necessary, further user inputs that lead to a correct representation of the real system in a company-specific manner, such as linking logics,
- an update process that includes current states or input parameters into the system,
- a validation of the model to verify that the generated model correctly represents the processes and
- a connection of the simulation model to the real production control, in order to be able to use the Digital Twin as a support tool.

2. Results and Discussion

The testfield for the approach presented consists of a mid-size factory with three halls and a stockroom. Objects are known from the inventary list, but mostly not documented in CAD. First attempt has been conducted for an overall factory planning scenario which comprises all object types given, but pipelines. The developed framework has been tested using real-life data. The overall recognition rate is high, although the environmental impact is quite negative. More than 66 procent of all object can be trully recognized. However, the recognition procedure is sensitive. It comprises significant issues which need to be resolved. At general: objects with a unique shape like a hanging crane can be recognized easily (Figure 4). During the analysis of the outliers (objects which were either not recognized or recognized false) three main challenges became apparent, which cause the failure of recognition: occlusion, small test base and overfitting.

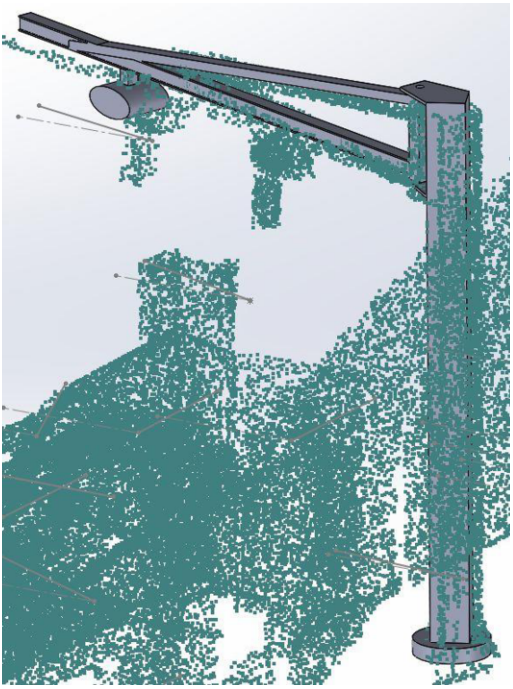

Figure 4. Recognized object: hanging crane.

A single part based algorithm fails completely in case of a significant occlusion. This becomes clear when two or more objects are assumed as one cluster (Figure 5). Although this case does not rarely occur in a factory, it will not be investigated further, but resolved by an additional loop, where clusters which contain more than one object are subdivided manually and then processed separately.

Scanning with a scanner device in the height of approximately one meter above the ground of the factory has a basic drawback that the top area, especially the roof, of these large objects, which are mostly machines, can not be acquired properly. In order to create a closed geometrical object, the top is being approximated by a plane. That is not only a dimensional deviation, but also reduces a possible distinctive characteristics of the object. This drawback is enforced by a basical structural difference between the test object, which is derived from a CAD model by using a virtual scanner and the scanned object.

Overfitting is not obvious, but its impact is ubiquitous. All three used CNN frameworks provide similar results and are sensitive on changes (e. g. input data quality). This implies a strong overfitting. The attempts to reduce overfitting lie in the extension of test base by more model variants.

Figure 5. Impact of occlusion.

This approach has weakness due to the small test base. Here, verification in larger space with more complicated scenes and different types of repetitive objects is needed. A collection like ModelNet for objects in a factory would be supporting. Like for similar studies with a different solution approach [24], some other limitations of this study should be clarified for future research:

1. Utilizing architectural domain knowledge to prevent acquisition of huge unnecessary data. A prescan which identifies the object and its bounding box would be helpful. Furthermore, the identification and evaluation of labels could reduce time for recognition. Prevention of outliers, likeundesired reflexion, would reduce the amount of data.
2. Improve the robustness of recognition methods by better training and continuous learning. Combination of a primar and a secundar recognition algorithm would be a solution,e. g. in case of occlusion [25][26].
3. Better integration of singular steps. Basically, it is about reverse engineering, which was included in leading CAD systems a decade ago. Assuming a fast and reliable

recognition algorithm, it could be implemented as a module in a CAD system and integrated into PLM as an object recognition module.

3. Conclusions and outlook

This paper advances the realm of generation of a Digital Twin in the most automated way in a built environment with complicated scenes (e. g. indoor environments with repetitive, irregular-shaped objects, and noisy measurement data as input). With this, the Digital Twin and the use of discrete event simulation provide manufacturing companies improvement potential for production systems leading to cost savings. It was shown how the overall procedure for the automated generation of a Digital Twin can take shape, which information is required and how it is stored in a useful and process-oriented way.

Future research can be conducted in four directions. First, the effectiveness of the proposed approach should be tested on other complicated cases with less obvious repetitions to make the procedure more stable [24]. Secondly, although the results of the laser scanning are promising, this way of shape acquisition is expensive and, therefore, it must be investigated which alternatives, e. g. photogrammetry, can be useful in term of accuracy and data volume [27]. The usage of video camera looks promising, but does not fulfil the accuracy requirements at this time. Thirdly, more advanced object recognition or computer vision methods can be selected to improve the semi-automatic or manual object generation [28]. The object recognition can be improved in multiple ways. Expanding model library would improve the training procedure and reliability of results. Fourthly, the process chain as such contains of several step and can be improved in term of performance and stability. Further simplification can be achieved by using intelligent templates [29] ensuring a deeper modularity [11]. Use of an alternative recognition method with multiple representations can be taken into account too [30].

Acknowledgement

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Analysis of Phenomena in Safety Systems Made of Hyper-Elastic Materials - Selected Issues

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Abstract. The article describes the process of experience building and knowledge shaping on the example of the study of phenomena occurring in the structure of polymeric safety buffers. A real example has been used as a normative qualification criterion allowing the security team to operate. The analysis of physico-mechanical properties of non-linear polymeric material of cellular structure was performed by considering the proposed mathematical description of the issues, based on experimental bench tests and using computer numerical methods. The work is devoted to extending the knowledge of processes occurring during critical interactions in safety systems based on polymer structures. To develop a methodology for identification of phenomena and design of products dedicated to minimizing the effects of accidents. Propose modern methods of verification and selection of passive safety systems. The conducted works were of a multi-criteria and multidisciplinary character guaranteeing direct translation of results and use of effects in other engineering techniques.

Keywords. polymer buffering units, hyperelasticity, material damping

Introduction

Energy-absorbing elements are used to limit the effects of dynamic loads created by an emergency. Made of hyper-elastic materials, they are used among others in cars (as elements of suspensions and bumpers), aircraft landing gears, as well as in vertical transport systems. In the design process, the analysis of necessary issues requires considering many different phenomena, such as: plastic deformation, cracking, or energy dissipation due to friction.

The methodology of structural design, particularly for the aviation and automotive industries, is based on the use of new materials: plastics and composites, as alternatives to traditional materials. Modifications of structures to minimize the effects of failures, accidents, collisions are carried out to achieve the highest possible energy absorption at low system weight. [1, 2]

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The processes required for consideration are complex and often highly non-linear in nature. For this reason, it is difficult to assess the behaviour of an energy-intensive element. Design processes aimed at producing a system from new materials, e.g. polymers, complicate the issues. It is required to use cognitive, research and analytical engineering techniques of more than subject matter character.

The article describes the process of experience building and knowledge shaping on the example of the study of phenomena occurring in the structure of polymeric safety buffers. A real example has been used as a normative qualification criterion allowing the security team to operate. Critical case of passenger lift cabin failure, in the context of passenger safety and lift structure strength, was considered by analysing the elastomeric safety unit. The analysis of physico-mechanical properties of non-linear polymeric material of cellular structure was performed by considering the proposed mathematical description of the issues, based on experimental bench tests and with the use of computer numerical methods. The influence of load history, structure degradation and load velocity on changes in buffer operation character were investigated.

The aim of the verification was to extend the knowledge of processes occurring during critical interactions in safety systems based on polymer structures, to develop a methodology for identification of phenomena and design of products dedicated to minimizing the effects of accidents and improving the safety of people and equipment, to develop modern methods of verification and selection of passive safety systems. The conducted works were of multi-criteria and multidisciplinary character guaranteeing direct translation of results and use of effects in other engineering techniques.

1. Characteristics of polymer buffering units

Safety buffers are a safety element required in a passenger crane assembly according to european standard [3]. The purpose of using the unit is to protect the crane and passengers from the effects of the cabin exceeding the permissible lower position and hitting the elements located in the elevator pit.

An incident when the cabin overruns the bumper is a danger to both the passengers and the structure of the crane. Kinetic energy of a moving cabin about mass 950 kg, falling freely from a height 1 m kg had to be dispersed by the bumper on a distance 0.1 m. Therefore, high dynamic loads are generated.

Buffer bumper solutions can be divided according to the following work characteristics: linear (spring), energy dissipating (hydraulic), energy absorbing and dissipating, non-linear (elastomer).

Foamed materials are used for elastic and damping elements in safety systems for cranes, vehicles and as machine foundation systems. The use of polyurethane structures is supported by the ease of designing favourable physico-mechanical properties, technology and low price of products. PUR is a thermoplastic material obtained by polyaddition of aromatic or aliphatic diisocyanates with compounds containing at least two hydroxyl groups, e.g. diols or polyethers. Different properties of the materials obtained are determined by the isocyanates and polyols contained in them.

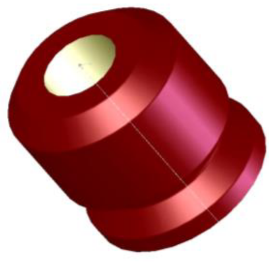


Figure 1. The tested buffer of the company EN2 ETN GmbH.

The materials used to build elastomeric energy-dissipating buffers are foamed polyurethanes such as Cellasto® (BASF), Diepocell® (P+S Polyurethan-Elastomere GmbH & Co. KG), AUTAN® (ACLA-WERKE GmbH), Cell-PU (ETN GmbH). The shape of the tested buffers are presented on figure 1.

2. Analysis of phenomena in a system with an elastomeric element

Using the classic description of a machine assembly subjected to loads in the form of vibrations extended by the performance characteristics of polyurethane elastomers [4-6] the description of phenomena occurring during the operation of buffer assemblies is described by a mathematical model reduced to the mass of the machine m, according to the scheme shown in figure 2.

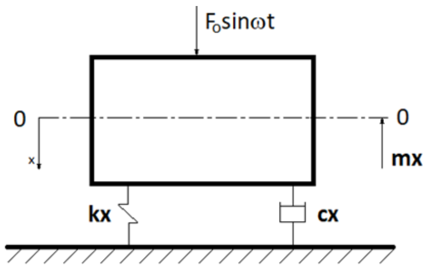


Figure 2. Diagram of the vibration system.

The layout shown can be described with the use of the equation (1):

$$mx'' + cx' + kx = F_0 \sin \sin \omega t \quad (1)$$

where: mx'' - inertia, cx'-internal friction force, kx - restoring force.

Internal friction is determined by the mechanical loss factor d i.e. $tan\ \ angle\ tan\ \delta$. Tangents δ is the angle between the source deflection arrow and the final deformation.

The properties of the mounting springs affect the natural frequency of the system (2):

$$\omega_{rz} = \sqrt{\frac{c}{m}} \quad (2)$$

where:

$$c = \frac{F}{X_f} \quad (3)$$

$$\omega = 2\pi n \quad (4)$$

If the elastic deflection X_f is in [mm] based on equation (3) it is possible to designate critical frequency n in [Hz]. Internal friction and restoring force determine the size of resonant frequency and the increase in V_D amplitude. Dimensionless V_D value is the solution of equation (1). In a mounting system, the system's response force can be estimated according to dependency (5):

$$V_D = \frac{F_{reszt.}}{F_{dost.}} = \frac{1+jd\lambda}{1-\lambda^2+jd\lambda} \quad (5)$$

V_D should be considered in the selection of the protective elements. Damping coefficient of the material determines the effectiveness of vibration damping, which for the system under consideration can be determined from dependency (6).

$$\eta_D = (100 - V_D) \tag{6}$$

The desired system damping performance (as high as possible) can only be achieved with a low force ratio F_{dost} i $F_{reszt.}$ i.e. a small coefficient $V_D \rightarrow \lambda \rangle \sqrt{2}$, $d \approx 0$.

Based on the results obtained, the natural vibration frequency for the critical load case and the desired damping performance of the system were determined. The model was used for selection and commercial selection of the polyurethane elastomeric protection unit for research works. It was assumed that the element should be characterized by the lowest possible mechanical loss factor d, while low natural frequencies were achieved.

3. Experimental Research

The buffer EN2 was made out of poliuretan with the trade name PUR Cellasto from the company ETN GmbH. In order to determine the physical and mechanical properties, basic tests of the elastomeric material were performed. The tests were performed in accordance with the guidelines of the european standard [3]. For the tests the specimens, cut out of the buffer: rectangular beams (static tensile tests), cubic cubes (static compression tests) were used.

It has been assumed [2], that there is an asymmetric characteristic of operation of PUR foam elements in compression and tension. Therefore, the experiments included static tension and compression, in range of strain up to 80% of nominal strain, and free compression at speeds: 0.1 mm/s, 1 mm/s, 10 mm/s, 40 mm/s in the range from 10% to 80% of nominal strain. Figure 3 shows the characteristics of σ(ε) PUR material.

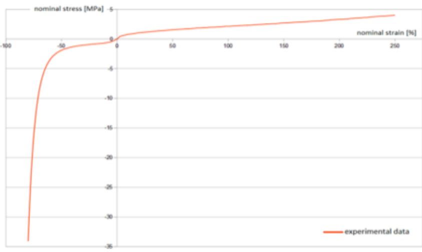


Figure 3. Characteristics of nominal axial stresses as a function of axial strain of specimens cut out of buffers [8].

Figure 4 shows the registered tensile (a) and compressive (b) tests. Cellasto PUR characteristic values were used for numerical identification of material in FEM systems and preparation of functional models of buffer units.

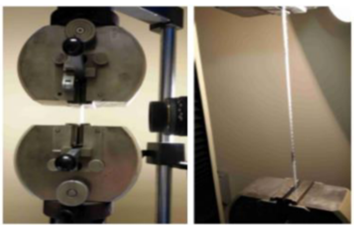
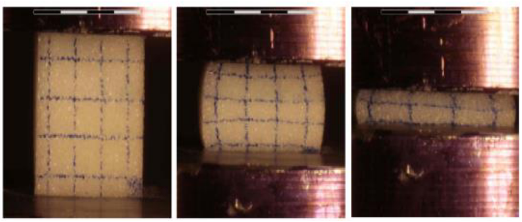
a)  b) 

Figure 4. Executing experimental tests [8].

The polyurethane from which the buffer is made has a cellular structure. In order to characterize the structure of the material, tests were performed using optical and scanning microscopy. It was found that the sizes of spherical, open pores are uneven in the entire buffer volume. They depend on the course of foaming during production. The pore diameter ranges from 0.1-0.2 mm for less and 0.4-1 mm, for more foamed areas. The resultant density of the tested material is 0.5 g/cm3.

The nominal strain curves obtained from the compression tests are shown in figure 5. Comparing the obtained characteristics of the new and tested material, it was found that the material with a load history has a lower stiffness in both compression and tensile (figure 6). The evaluation of changes at the level of PUR material structure and mechanical properties resulting from the deformation of the buffer element during operation was performed. The verification was based on experimental tests and microscopic observations.

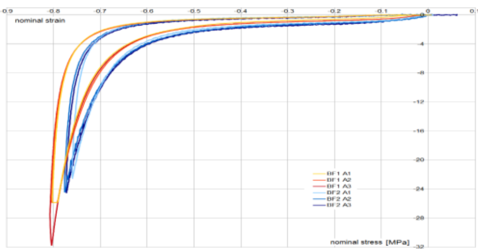


Figure 5. Characteristics of nominal axial stresses as a function of axial strain of specimens cut out of buffers [8].

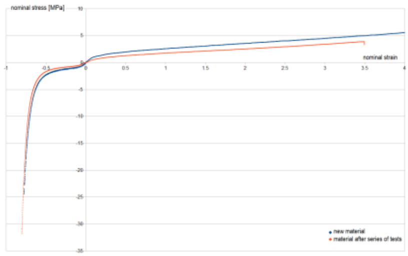
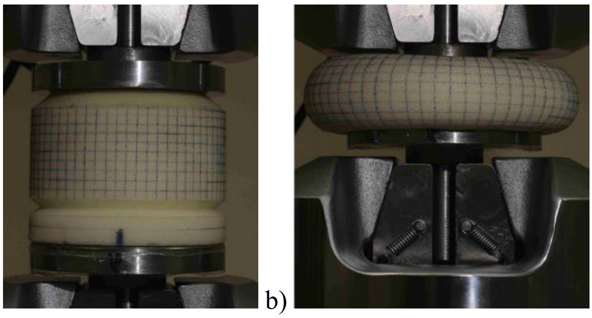


Figure 6. Characteristics of nominal axial stress as a function of axial strain for new material and with strain history [8].

External evaluation did not indicate any permanent changes or buffer damage. After cutting into smaller samples, damage to the material structure was noticed on the inner cylindrical surface of the buffer.

An evaluation of behaviour of the physical buffer element at speeds: 0.1 mm/s, 1 mm/s, 10 mm/s, 40 mm/s in the range from 10% to 80% of nominal strain was carried out. In order to assess the effect of the relaxation phenomenon [2], the tests were carried out in three rounds, at an interval of two weeks each. Figure 7 shows an example of the implementation of the test.



a) b)

Figure 7. Buffer a) before the experiment b) during the experiment – nominal strain 80% [8].

The phenomenon of stress relaxation in the material structure was observed. Figure 8 shows the time course of the buffer compression test. It should be noted that despite maintaining a constant position of the machine head support, the axial force decreases, which suggests that there are changes in the stress condition of the specimen.

The recorded loading and unloading characteristics are arranged in hysteresis loops, the field of which indicates the amount of energy dissipated by the energy element under investigation. The study did not consider the issue of internal damping, but it is worth noting that in one full cycle of deformation, the field of hysteresis loops represents up to 60% of total deflection energy. Figure 9 shows the change of buffer deformation energy during loading and unloading obtained by integration of the axial force course in relation to displacement.

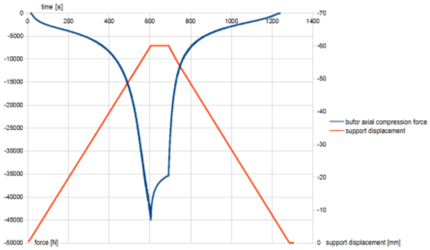


Figure 8. The course of the buffer compression test over time [8].

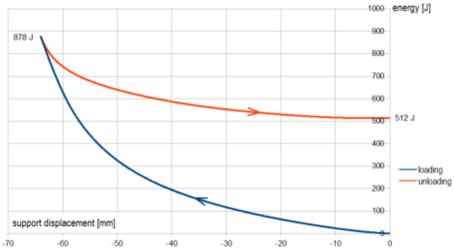


Figure 9. Deformation energy of the buffer - the direction of the course in time was indicated [8].

4. Model of material

Different models of hyperelastic materials are described in the literature. Each of them has its own characteristics and was created to describe selected materials [9-20]. For the purposes of the study, the assumptions of the material models were analysed and the results of the research were discussed. The calculation of model coefficients was based on the tabular representation of the material curve, created on the basis of experimental results shown in figure 3. The models proposed by Ray W. Ogden in 1972 and R. Hill and B. Storåkers' so-called 'hyperfoam' model were considered.

Among the considered models the Hill-Storakers model, which is a modified Ogden model, proposed by R. Hill and B. Storakers for the needs of modeling isotopic foamed materials. The model assumes that the behaviour of the material during deformation can be described by a function of the form deformation density and on this basis the relationship between stresses and deformations can be derived. In this case the deformation energy density is described with the dependence (7) [21][22]:

$$W = \sum_{i=1}^{n} \frac{2\mu_i}{\alpha_i^2} [\hat{\lambda}_1^{\alpha_i} + \hat{\lambda}_2^{\alpha_i} + \hat{\lambda}_3^{\alpha_i} - 3 + \frac{1}{\beta_i}\left(J_{el}^{-\alpha_i\beta_i} - 1\right)] \tag{7}$$

where:

$\lambda_1, \lambda_2, \lambda_3$ – the deviatoric stretches,

J^{el} – the elastic volume ratio,

μ_i – are coefficients related to the initial shear modulus,

βi – are coefficients related to the Poisson's ratio.

It appears from the considerations made that the third degree Hyperfoam model based on coefficients according to Table 1 best represents the behaviour of the material. It provides both greater stability of calculations and better adjustment to experimental data at higher deformations. The limitation was the stability of the analyses due to high local stresses in the contact areas. Plastic deformations in the model were allowed. The yield strength was determined from the values of permanent deformation from the compression tests. Figure 10 shows the relationship between stress and plastic deformation implemented for the verified material models. The results of the evaluation of the Hill-Straker's model of 3rd degree - Hyperfit are shown in figure 11. The parameterized description of the model was used in numerical analyses.

Table 1. Hill-Storakers model coefficients for degree n=3.

i	μ_i	α_i	β_i
1	-1.6925918891	0.00263931423	-0.213821998
2	2.3606046565	1.519090909993	0.2676923057
3	0.2411390007	-2.23355096391	-0.0882572061

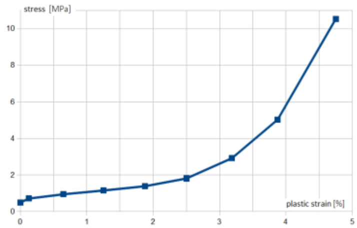


Figure 10. Plastic strain characteristic defined for researched material models [8].

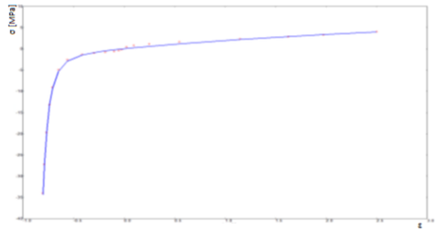


Figure 11. Results of evaluation Hill-Storakers 3rd degree model – Hyperfit [8].

5. FEM model analyses

The curves of the material tests were used in a similar tensile test in a virtual environment. Materials with a maximum engineering strain like several hundred percent require the use of a simulation curve of true stress – true strain. Using the stresses and deformations referenced to the initial section. True strain calculated according to the equation (8). True stress received directly from the uniaxial tensile test as the ratio of instantaneous force and cross-section sample.

$$\varepsilon_{real} = \frac{l_0+\Delta l}{l_0} = \ln(1+\varepsilon_{eng}) \tag{8}$$

Tensile simulations of PUR samples were performed. Curve true stress - true strain obtained from the simulation was compared with input curve, until convergence has been obtained. They allowed for the selection of the appropriate material model and selecting the appropriate description of the material curve. Figure 12 shows the simulation results.

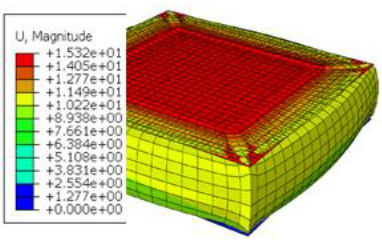


Figure 12. PUR test by Hyperfoam model – FEM (reverse engineering).

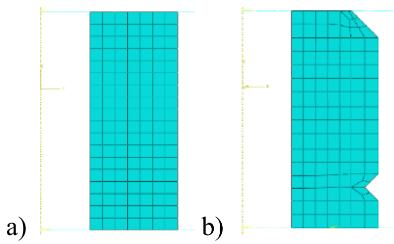


Figure 13. Buffer models used for analysis: a) simplified model, b) precise model.

The buffer work was analysed using two different geometric models. The first one was a simplified model, the second one included two peripheral undercuts. The axial symmetry of the buffer was used to perform analyses in two-dimensional space. The buffer cross-section model is placed between the elements reflecting the pressure plates. A rigid frictional contact was defined between the plates and the analysed unit. Four-node hybrid elements were used for cross-section analysis. Edge conditions were defined in the symmetry axis of both clamping elements. The load was given by linearly increasing displacement of the upper clamping element until a deflection of 80% was achieved.

It was found that the developed model of the material allows for mapping of the global buffer deformation. The buffer compression characteristics obtained by numerical analyses show deviations from experimental observations in the range of material expansion beyond the compression elements. The differences found were a consequence of the adopted approximations in mapping the material behavior. A comparison of the deformation of the actual object with the FEM model is shown in Figure 14. For better illustration, the results from the axisymmetric model are displayed in a three-dimensional form.

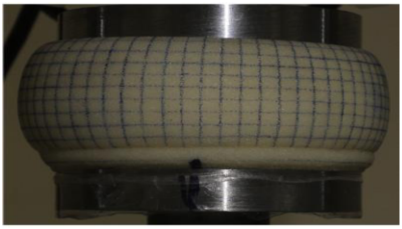
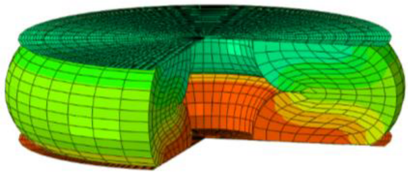
a)  b) 

Figure14. Comparison of the results of the buffer tests (a) with the results of the numerical simulation (b).

6. Summary

It has been proved that it is necessary to recognise and describe the phenomena occurring in the structure of the material used to manufacture safety systems and cooperating elements in order to carry out the process of designing and qualifying products.

The performed cognitive tests and numerical analyses showed the validity of the adopted process of proceeding in the scope of evaluation of phenomena occurring in highly stressed elements produced from materials with degressive-progressive non-linear deformation characteristics.

The research confirmed that the behaviour of hyper-elastic material is influenced by a number of phenomena, including in particular the Mullins effect, which manifested itself in the change of stiffness of the material under the influence of successive cycles of deformation.

The developed numerical model of the buffer, containing a description of the material prepared by the authors, made it possible to map the way the security unit works. The conducted numerical simulations allowed to mark the most stressed areas and revealed the essence of changes in the shape of the element. Based on analyses of numerical tests results it was found that the most significant phenomena occur inside the buffer, and more precisely on the internal cylindrical surface. It was justified that the key influence on the buffer's compression process is the axial-symmetrical hole, which stimulates the formation of phenomena resembling local loss of stability, consisting in the change of the compression process into bending. Peripheral cuts only increase buffer predisposition to the above phenomenon.

A concurrent method of design and numerical verification of protective elements possible to be manufactured from hyper-elastic porous materials was developed, which consists of the structural design of the component (system) numerical analysis of the assembly behaviour for critical cases and when it is necessary to identify the material of the experimental study. The issues described in the article, including experimental tests and structural identification of the behavior of elastomeric materials, are an important contribution to the development of a number of technical fields. The authors' experience as well as formulated observations and conclusions from the paper are the basis for design and research-implementation works in the field of developing safety systems for working machines. Because of the problems and issues described in the article: multi-criteria approach to the topic, development of new knowledge in the field of systems construction limiting the effects of failures and accidents, design, material engineering, identification and inference supported by a number of research at the structural and physico-mechanical level of the material, broaden the knowledge on a number of platforms for the exchange of engineering experience fit into the mainstream transdisciplinarity of the conference.

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Verification of Flutter Method for the Purposes of Building a Very Flexible Wing Generative Model

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Abstract. First step of aircraft design is calculation of initial parameters, based on assumptions determining flight parameters which designed aircraft should meet. During these calculations, it is possible to pre-detect structure instability called a flutter. These calculations are made based on the geometric parameters assumed in the first conceptual drawings of the flying vehicle. Assumed masses and speeds allow for preliminary analysis of forces acting on the structure. The next step is to determine the displacements and deformations occurring in the structure of the aircraft in different phases of flight and under different conditions. The article presents all the stages of wing analysis for a proposed stratospheric drone with a highly flexible wing structure. This analysis, after integration with CAD software, will allow for the preparation of a comprehensive generative model. The basic assumptions of the designed aircraft are: flight altitude, wings area, very extended or unlimited flight time, approximate flight speed, climbing time, hull parameters, rudder size and placement, wing profile and mass of the structure. These assumptions made it possible to carry out a preliminary analysis of loads, wing pressure distribution, lift force and total resistance force. The goal of the research is to develop a methodology of preliminary flutter analysis which can be easily integrated in the form of calculation backgound for generative model. This methodology has been developed to determine displacements, structure stability and critical vibration frequencies. CAD software after integration with constantly optimizing calculation software will allow the generation of optimal shape and structure rigidity for given initial assumptions.

Keywords. Flutter, elastic wing, drone, generative model, aircraft design.

Introduction

Designing modern aircraft requires confirmation of the strength and stability of all the elements of the designed structure. All newly designed aviation structures are analyzed in terms of possible flight parameters and loads occurring during flight. This analysis allows the determination of the strength limits of the structure. Based on such data, optimization is performed that streamlines the design and adapts the designed vehicle to the initial assumptions.

Large enterprises producing aircraft and other flying objest use tools developed for their own needs to assist in calculating the parameters of the designed aircraft. Smaller

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companies that develop and manufacture low-volume and single series aircrafts do not have software for this purpose.

The need is therefore to create software whose goal will be to support the design of highly flexible aircraft with light and ultra-light weight structure.

The article presents possible ways of aeroelastic analysis of the generative structure of an ultra-light stratospheric drone platform.

In order to facilitate the design of large load-bearing composite structures, with high flexibility and extremely low weight, it was decided to develop tools supporting the designer in the design of such structures. The tools are integrated directly in the CAD system. It have the form of generative model and integrate knowledge of composite structure design, composite strength, aeroelasticity of highly flexible structures, aerodynamics, composite shaping technology, flight mechanics and aircraftdesign. Generative models include solutions that integrate design automation methods, comprising integration of complex structures with many elements based primarily on experience in the automotive industry [1] [4], specific rules for the design of composite elements shaped in molds in analogy to experience in the field of shaping stamping dies [2] as well as modeling techniques and automation of the design of complex surfaces. They all constitute the basis in modeling in the automotive industry, aviation and plastic processing, in particular the design of wrrapeable and non-wrrapable surfaces [3]. Generative models and various aspects of this methodology were used to develop the experimental HALE UAV (High Altitude Long Endurance Unmanned Aircraft Vehicle) project called Twin Stratos.

1. Verification of aeroelastic phenomena

During the flight there is a occurrence of several dangerous aeroelastic phenomena. The most important are presented below:

1.1. Static type phenomena:

- Divergence - aerodynamic forces increase the angle of attack of a wing which further increases the force.
- Control reversal - where control activation produces an opposite aerodynamic moment that reduces, or in extreme cases, reverses the control effectiveness.
- Flutter - the uncontained vibration that can lead to the destruction of an aircraft.

1.2. Dynamic type phenomena:

- Self-excited vibration (flutter) - The airframe's self-excited vibrations occur at a certain flight speed, when at least one of natural vibrations frequency of the structure is combined with external stimulation vibrations frequency. The phenomenon itself is a complex dynamic system conditioned by aerodynamics, rigidity and mass characteristics of the airframe.
- Buffeting - Buffeting occurs when one of the forms of the airframe's own vibrations is stimulated by an external source. Most often, such a source may

be the impulse caused by the entering to the propeller streams or entering to the turbulence area with a regular oscillating character.

Due to the need to analyze each newly designed aircraft, the main subject of the analysis in this article will be determination of stability and aeroelastic analysis of an aircraft with a highly flexible load-bearing structure.

The main steps for checking the correctness of the designed structure are presented in the Figure 1.

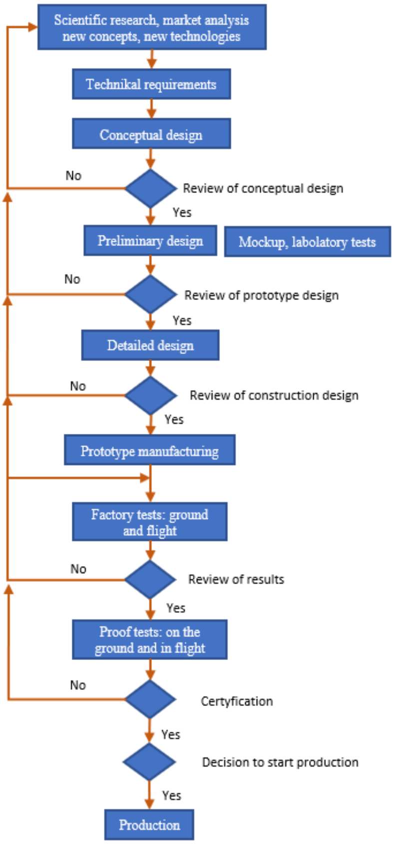

Figure 1. Algorythm of the presented aircraft designing process [4]

2. Preliminary analysis based on the center of gravity position of aircraft components

The basic analysis of the aircraft flutter occurence possibility is based on recommendations determined on the basis of testing existing aircraft of approximate design. Historical guidelines clearly determine the possibility of flutter depending on the location of the center of gravity of the elastic elements to the aerodynamic center of this component. This is the easiest method that allows to determine whether there is a possibility of this phenomenon in the proposed structure.

This method is called "stiffness tests" and to perform it, the stiffness of individual parts, the location of their centers of gravity and their resistance to forces are determined.

Due to the analysis of low-weight aircraft and high flexibility, this analysis is not accurate enough. This method determines whether there is a possibility of flutter occurrence in the designed object and whether it should be further analyzed or there is no possibility of this phenomenon in analised assembly [5], [6].

3. Analysis based on simplified mathematical model and aircraft shape parameters

This analysis is the next stage of aircraft testing. It involves testing a simplified mathematical model of the parts which are most vulnerable to flutter, i.e. parts that were considered risky during the analysis based on the location of the main gravity points of the structure.

This type of analysis is performed based on the basic parameters of the designed aircraft. Due to the need to simplify the analysis, the external shape is replaced there by simple two-dimensional gemometric figures. Then the parameters of the elements on the basis of which they were created are assigned to these figures.

Due to the availability of software, it was decided to use free access software for academic purposes to conduct the analysis in this step. The literature review of the available software has shown that the available means for performing the assumed aeroelastic analysis are the programs presented in table 1.

Table 1. Software with license aviable for students.

Software	**Basic informations**
Unsteady Vortex Lattice Method (UVLM)	Computation code NANSI (Nonlinear-Aerodynamics/ Nonlinear-Structure Interaction) which combines an Unsteady Vortex Lattice Method (UVLM) and a nonlinear beam theory. The UVLM is particularly useful in case of lowaspect- ratio wing or delta wing because the method is able to predict 3D effects. [7]
Program SHARP (simulation of High Aspect Ratio plane)	Proposed by Murua in SHARP program (Simulation of High Aspect Ratio Planes) using UVLM with a displacement based geometrically exact beam theory. [8]
Dreli ASWING	Some models are dedicated to high-aspect-ratio wing like Drela's program ASWING. This VFA conception tool combines a nonlinear isotropic beam formulation with an unsteady lifting line theory. [9]
UM / NAST. (University of Michigan / Nonlinear Aeroelastic Simulation Tool)	More recently, Shearer and Cesnik have developed a Matlab toolbox called UM/NAST. (University of Michigan/ Nonlinear Aeroelastic Simulation Toolbox) made up of a strain-based geometrically nonlinear beam formulation linked with a finite state two-dimensional incompressible flow aerodynamic theory proposed by Peters and al. [10]
Riberio in Matlab Aeroflex	Operating principle similar to UM / NAST. (University of Michigan / Nonlinear Aeroelastic Simulation Tool) [11]
NATASHA (Nonlinear Aeroelastic Trim and Atability of HALE Aircraft)	Because aeroelastic tailoring exploits the anisotropy of composite materials, a suited reduced order model must take this anisotropy into account. This capability resides in the Matlab toolbox proposed by Patil and Hodges called NATASHA (Nonlinear Aeroelastic Trim and Stability of HALE Aircraft) coupling an intrinsic beam formulation with Peters' theory. [12]

Details of comparison of available software for analysis of aerodynamical instabilities is presentaed in table 2.

Due to further analysis of available research environments, Unsteady Vortes Lattice Method and UM / NAST software were eliminated. The reason for the elimination of the software was the inability of modeling of aircraft specified for the design assumptions. This software focuses on the analysis of vibrations on the basis of moving elements, such as dragonfly wings.

After installing NATASHA, SHARP and Matlab Aeroflex software, difficulties were found in the operation of SHARP software, and due to that fact it was decided to opt out of this program. The NATASHA program has been eliminated because of low intuitiveness and ease of use.

Having analysed available software in this way, Matlab Aeroflex was selected for the next stage of analysis of the designed ship.

Table 2. Comparison of software for aerodynamical instabilitiesanalysis.

Program	**Environment**	**Accuracy**	**Proposed confirmation of the result**	**Licence**	**Ease of use**	**Aerodynamic excitation flutter**
Unsteady Vortex Lattice Method	Author's	Very high	Wind tunel	Free for students	good	no
Program SHARP	Author's	high	Numerical	Free for students	good	no
ASWING	Mat-Lab	high	Numerical	Free for students	sufficient	yes
UM / NAST.	Mat-Lab	high	Wind tunel	Free for students	sufficient	yes
Riberio in Matlab Aeroflex	Mat-Lab	Very high	Wind tunel, numerical	Free for students	good	yes
NATASHA	Mat-Lab	Very high	Wind tunel	Free for students	sufficient	yes

4. Analysis based on an detailed virtual 3D model

This type of analysis consists in generating a 3D model of the designed aircraft, and exactly all its parts together with the associated type of materials and methods of fastening between them. This method allows determining the possibility of flutter phenomena with very high accuracy. This type of analysis allows testing under different flight conditions of the designed aircraft, and hence for different forces acting on it.

The problem of this analysis is the need to use detailed model the whole structure so it is intended to use in the last phases of design. It results in extended time of the whole analysis and increase of hardware requirements necessary to perform the given coupled aerodynamical together with stress–strain analysis [6].

5. Analysis based on an accurate physical model of the designed aircraft

The last type of analysis is to determine the probability of flutter on the basis of a scalable model of the designed aircraft or part that is exposed to this phenomenon. The model is exposed to load conditions that were determined in previous analysis steps. Usually this type of test is performed in wind tunnels or on testing platforms adapted to test a specific part of the aircraft. This analysis can also be based on observation of an existing aircraft in which the part necessary for testing has been installed. At this stage of work, prototypes of aircrafts are usually built, which are then flown over the entire range of parameters for which they were tested numerically. It is important that at this stage of research the safety factors of the aircraft are not taken into account, and its parameters are checked experimentally in extreme conditions [8], [9]. Research is usually finalized with detailed flight testing of prototypes.

6. Analysis of designed UAV process

The aircraft design process is iterative. After the first market analysis preliminary technical, economic and environmental impact assessments are then carried out. This stage usually ends with the formulation of technical and economic requirements [10], [13].

The next stage inculdes the conceptual design, also called the feasibility study, which defines the basic parameters of the new concept. There are also drawings showing its appearance and arrangement of the device. Mass distribution, aerodynamic properties, stability, performance and loads are further analyzed. The structure is designed and tested. Finally, costs are analyzed. All these analyzes are carried out in the absence of very necessary accurate information, so they should be carried out by the most experienced designers.

This process is repeated many times. Usually, in each subsequent iteration, designers learn more and more about the new aircraft and bring its properties closer to the assumed ones.

Then we proceed to the implementation of the initial design, which aims to verify the assumptions adopted at the conceptual design stage and determine the solutions used.

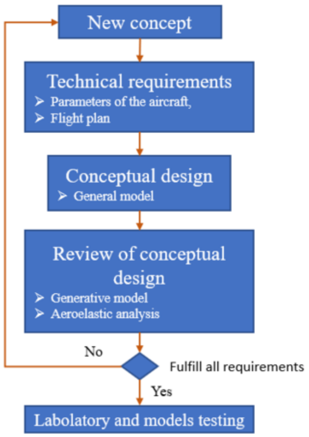

Figure 2. Algorythm of the presented aircraft analysis process. Generative model.

In order to clearly define the way or ways that were used during work on the solution of the presented problem, it was necessary to understand the work pattern when designing similar aircraft. This scheme is presented in the pictrue (see Figure 1). During work on a specific issue, the focus was on the first three steps with a feedback (see Figure 2). The problem, however, is the combination of the results of the analysis carried out with the preliminary data to the project. At the stage of such an early analysis, it is not possible to combine data with results and introduce automatic change of assumptions.

One of the methods to deal with this problem is to automate the design process by applying Generative Modeling. It involves building associative CAD models in the CAD system environment. Model features are controlled through identified relationships and design knowledge.

The construction of generative models consists in enriching the usual geometric CAD model with design and design knowledge introduced into the system using various forms of its representation, such as:

- Parameters - defined by numerical or descriptive values,
- Formulas - the most common mathematical dependencies,
- Rules and reactions - used e.g. for the automatic selection of standardized parameter values or parameters that the constructor reads from charts or tables in traditional design,
- Check - by which the model user may be notified in the event of failure to comply with certain conditions or exceeding certain design restrictions,
- Design tables and their configurations - enabling you to control the activity of sets of multiple parameters,

- Knowledge templates - which are a form of knowledge management and sharing.
- To perform more complex design calculations, you can use the internal capabilities of the CAD system as well as external software such as Excel or MATLAB / Simulink.

The "Riberio in Matlab Aeroflex" is selected for preliminaryaeroelastic analysis. This software allows for very quick structure analysis and helps determine its critical points. This software is written in the MATLAB environment which enables very large modifications of model assumptions and test conditions [11], [15].

7. Twin stratos, High Altitude, Long Endurance Unmanned Aerial Vehicle (HALE UAV)

Figure 3. Designed HALE UAV.

For the purpose of analyzing a specific aircraft (see Figure 3), an analysis of its parameters was performed. All variables necessary for calculations were pre-determined, such as the lenght of the wings, area of the wing, wing profile, average wing chord, etc. This was the determination of the parameters necessary to perform the first step in the design algorithm of this ship (see Figure 2).

At this stage, a preliminary sketch of the aircraft was created along with the assumed rear tail system. It was assumed that the aircraft would be a double-hull structure with a constant chord wing between the fuselages. Due to the flight mission plan and tasks to be performed by a given aircraft, the flight altitude, speeds and payload were assumed.

After determining the range of parameters included in the analysis. Next stage requires the use of preliminary calculations of loads, lift and resistance as well as structural adjustment.

The wing profile with its center of gravity is shown in Figure 4. Due to the possibility of unfavorable effects of the flutter in these elements, it is necessary to carry out a more detailed analysis of the given elements.

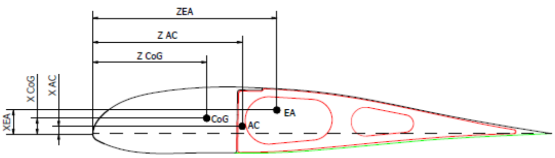

Figure 4. Position of elastic axis, center of gravity and aerodynamic center in the wing crosssection [12].

To increase the accuracy of the analysis and confirm or eliminate this hypothesis, the wings were analyzed using the Aeroflex environment [14].

Initial assemblies were included into the previously prepared environment and then all parameters were optimized for the intended flight altitude and mission objective [16]. Due to the difficulty of modeling the double-hull system in a given environment, the system was simplified and only the parts of the aircraft that showed the possibility of the flutter phenomenon were tested.

Both hulls, tail and part of the wing connecting the hulls were omitted. It has been fitted with a profile and chord to the results of the analysis and optimization of the outer wing [17].

The pictures below show the maximum displacements obtained for an example which has the flutter has been prepared (see Figure 5), and the designed and optimized aircraft. For an accurate presentation of the optimization process, the figure below shows the wings for which the average chord of the wing was changed (see Figure 6).

The change in the average wing chord, and more precisely the extension of this parameter, allowed to reduce the vibrations until this phenomenon is completely stopped. An analysis was carried out for ten different lengths of average wing chord. Figure 6 shows results of displacement of the designed wing tip for 10 values of length of the average wing chord.

In this way it was determined that for the designed aircraft the flutter phenomenon occurs for an average chord lenght from 1 meter to 1.2 meter. Other parameters remained unchanged. Due to this study, it was determined that the designed UAV does not show flutter tendencies after fulfilling the assumption that the average chord of the outer wing with respect to the hull axis should be higher than 1.3 meters. In designed UAV length of average chord is equal 1.45 meters.

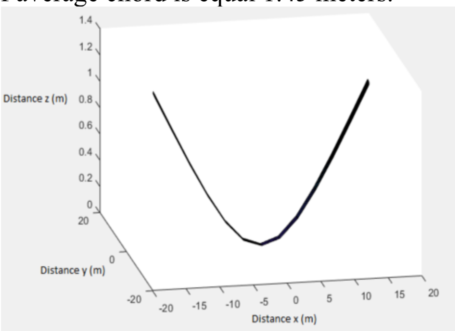

Figure 5. Example with flutter.

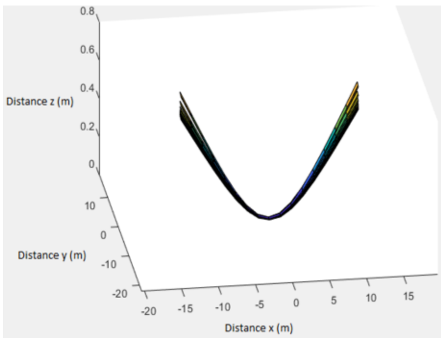

Figure 6. Optimization process desplacements.

The most important results of the analysis are presented in the figures. The results of the wing in which the flutter phenomenon occurs (see Figure 7) were compared with the results of the wing of the designed aircraft (see Figure 8), for which the optimization of the average chord of the wing was carried out.

Comparing the obtained results, it can be clearly stated that the flutter phenomenon should not occur in the designed structure after numerical optimization.

Due to another software limitation, we cannot simulate a linear speed change. This would require specifying a very large number of speeds for which the object would be examined, and so the initial test speed would always be zero.

The optimized design of the wing allowed the selection of parameters in such a way that even a very large change in the force acting on the wing did not introduce them into self-excited vibrations. As it can be seen in the Figure 8. Wing tip displacement stabilized automatically, even though its initial state was air pressure at 0 [km / h] and at one moment it was increased to 100 [km / h]. Because of this change in speed, we can observe a large wing tip displacement stroke that occurs during the first five seconds of the test. Then the structure stabilizes itself at a 0.5 meter displacement of wing tip.

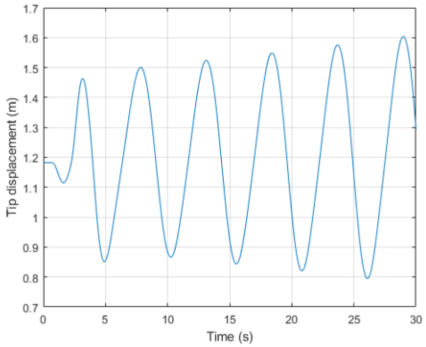

Figure 7. Example of flutter wing tip vibrations altitude.

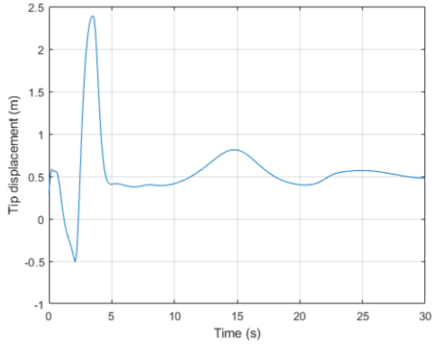

Figure 8. Designed plane wing tip vibrations altitude.

The tested structure shows the ability to very well damp vibrations very well.

The analysis allowed for significant changes to be made to the design of the planned aircraft. The next stage of work related to the described project requires to make a scaled model of the aircraft and check the results of calculations in an experimental way.

8. Discussion and conclusions

Unmanned aerial vehicles of this type can perform many days of missions that would be very difficult and expensive to perform by a human. The technology being developed will allow the study of very high layers of the atmosphere and the development of accurate maps of air currents at high flight altitudes.

The analysis presented in the article allows errors to be excluded at a very early stage of aircraft design. The method is accurate enough to be able to make changes to improve the design.

Creating the presented method of analysis required the use of mechanical engineering based on the laws on which preliminary calculations, IT techniques and mathematical programs were performed, which simplified the analysis process and material engineering on the basis of which the initial properties of the structure were determined.

The problem of the presented analysis is the inability to model the exact properties of structure rigidity. All parameters are approximate and very accurate results cannot be obtained. In addition, it is not possible to design the initial velocity of the aircraft, which is modeling the air impact on the analyzed parts.

At the concept stage, the external shape including the UAV supporting structure was determined. All assumptions were used to perform initial calculations and necessary analysis.

For highly flexible structures, there is a need to verify aeroelastic phenomena at an early design stage. This allows you to reduce the defectiveness of the conceptual design.

Due to the need to integrate the presented analysis into the generative model, in this article have been presented methods easily to combine with model variables. The mass analysis carried out enables integration into the generative model.

The article presents methods of analyzing aeroelastic phenomena available for students. Becouse of the possibility of using the analysis results in the generative model, the Riberio in Matlab Aeroflex program was selected.

Due to the lack of a real model of the examined object, it is not known if the results are correct and require confirmation in a more advanced environment. The analysis confirmed the supposition that flutter phenomena may occur in the examined elements.

Acknowledgement

We wanted to express gratitude for SkyTech eLab company for providing documentation of the Twin Stratos UAV project for research purposes.
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Proposal of the Coupled Thermomechanical Model of a Crank Mechanism

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Abstract. The aim of the paper is to propose analytical coupled thermomechanical model of the crankshaft system, which includes the mutual interaction between thermodynamic and mechanical phenomena occurring in engines. The most relevant dynamic effects observable in the crank system are connected with its kinematics. When the mechanism operates there are also additional effects corresponding with stress, strain and thermal fields. Elastic properties of the system parts and changeable stiffness of the fuel-air mixture cause different dynamics of the entire device. The authors assumed that rigid motion of the crank mechanism, parts deformation and thermodynamic effects and their mutual dependencies will be included in the modelling process. Elasticity of the crankshaft system components is the reason for the difference between a rigid 'ideal' motion and the real movement of crankshaft elements. In most cases, it is enough to assume linear elastic material features based on the relatively high stiffness of the system preventing big deformations. This ensures small displacements and the correctness of the applied model. The performed investigations have shown an influence of the crank system flexibility on the overall device response. Moreover, the parameters that change due to thermodynamic and mechanical properties of the working medium were taken into account. The authors have applied simple engine cycles (Otto, Diesel or combined model) for determining engine load including the connection between mechanical and thermodynamic state variables. This caused another decrease of the total system stiffness. Further numerical testing proved a visible effect of the applied approach in the global system response. The main discrepancies are observable in natural frequencies and vibration modes. It can also be stated that the utilization of different engine cycles results in different engine features. The paper is concluded with an analysis of the existing systems and mutual reactions from the assumed phenomena. The authors have shown the necessity to take a transdisciplinary approach into account in order to model complex systems..

Keywords. Crank mechanism, dynamic model, engine vibration, coupled thermomechanical model, analytical modelling, Python and SymPy application

Introduction

Current trends in high efficiency engines and their low fuel consumption raise the need for the development of new concepts, application of extraordinary solutions and improvement of existing designs. This drives the demand for more sophisticated tools.

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Models previously used become inaccurate and require a process of recreation that takes into account more physical phenomena in order to enable them to be closer to reality. In order to meet these requirements, a transdisciplinary approach in the modelling process [3, 8] shall be considered. Scientific papers regarding a merge of different scientific or industrial disciplines indicate the proposed new approach of investigation might relevantly enhance solving problems in design process methodology [11]. Moreover, they present the transdisciplinary modelling as an extensive discipline that might enable obtaining much more comprehensive results comparing with conventional approach. Furthermore, in the world-wide literature one might encountered scientific articles presenting the transdisciplinary engineering as unspecified in terms of having a precise or unique definition what allows to consider the paper's topic as transdisciplinary [10].

Operational problems of engines are connected mostly with dynamic phenomena occurring during operation. In most cases, they are caused by elastic and inertial properties of the engine components. The combination of both results in engine part vibrations affecting the system operability [6, 14]. Moreover, a thermodynamic gas force which is the reason for limiting cycle existence impacts the system dynamics relevantly. In-depth analysis of the behaviour of system dynamics and a transdisciplinary approach can enable improved engine performance and its operational parameters.

Due to the complexity of the engine design, the designing process is based on a step-by-step improvement process, which leads to the final form of the particular motor. Designers are reluctant to introduce significant enhancements as that could lead to the unpredictable changes in dynamics of the motor. The satisfactory results of current engine designs are an effect of the confirmed industrial practice. However, due to power unit accessories design, more frequent process difficulties raise the need of new computational methods or models. Moreover, the required models should be accurate and fast. One of the projects related to engine equipment design was aimed on some efficient tools to be utilised in computations of Torsional Vibration Dampers [6]. The tools were required to be compatible with industrial specification and take into account manufacturing process of the object. The investigation carried out shows the necessity of transdisciplinary overcoming of limitations to ensure interchange of the older and current version of the part and dynamic conditions which lead to proper mechanical properties of the engine. For this purpose, a comprehensive engine model is necessary in order to allow precise system design process.

The main advantage of a transdisciplinary modelling are simultaneous considerations of mechanical and thermodynamic state variables. This allows for a complex analysis of the mutual influence of the system parameters on generated engine power. A typical approach assumes only the consideration of the mechanism geometry and dynamically independent changes of the rotational speed [1, 2]. Practical cases show there is an influence of the component vibrations on engine dynamics and operational parameters [7, 13]. These are mainly caused by additional stiffness of a fuel-air mixture or the crank system parts. This creates the need for a more detailed investigation of the engine complex model.

The engines main features are connected with the elastic properties of its components. Typically, they are not taken into account which limits the system vibrations [9, 12]. What is more, a crankshaft angle of rotation depends on the instantaneous state of the system. Even for a rigid crank and rod, the elasticity of the fuel-air mixture allows for small changes of the crank from its nominal position.

Inclusion of the thermodynamic effect provides the nonlinear relationship of the gas force and state variables.

1. Objectives and overview

The aim of the paper is to propose the analytical coupled thermomechanical model of a crank mechanism, which considers mutual interactions between thermodynamic and mechanical phenomena occurring in engines. The proposed coupled model emphasises the importance of a transdisciplinary approach in modelling of complex systems. The authors proposed a mathematical model of the crank-piston mechanism in order to enable theoretical analysis and the concept identification. The model analysis is intended to determine the kinematics and dynamics of the crank system and to analyse the impact of the selected system parameters on the total system dynamic response.

Because of a preliminary nature of the investigation carried out, it considers only the analytical and the numerical investigation on the object. The authors states that it is necessary to recognise particular model features before Finite Element Analysis and further experimental investigation. Moreover, it was decided to take into account only the simplest models of the considered phenomena. This was motivated by the papers aim to propose a model with the ability to represent the coupling and the mutual relationships between the state variables.

Based on the paper's aim and scope, the authors must apply some simplifying assumptions corresponding with the problem under investigation. The most relevant simplification is connected with the paper character. The aim of the study is to state a coupled thermomechanical model as previously mentioned. In order to achieve a model coupling, maximum simplifications of the particular phenomena are assumed.

Due to the aforementioned objectives, the following assumptions were adopted:

- the Otto cycle as a description of the engine working principle,
- a nonlinear kinematics of the crank mechanism,
- a dynamic value of crankshaft angle caused by the equilibrium of acting and resistance moments,
- numerical simulations based on the derived nonlinear governing equations,
- linear elasticity of the crank system reduced to the piston rod.

Based on the paper's introduction and objectives, it was stated that the realisation of the aim will need the following steps:

- modelling of a crank mechanism based on the selected assumptions,
- numerical simulations devoted to sensitivity analysis,
- the model identification based on the experimental data,
- the model aided investigation for recognition of the crucial discrepancies with currently utilised models.

Proper modelling of the mechanism and numerical simulations seems to be crucial for the presented work. The proposed assumptions make it possible to achieve preliminary results.

2. Crank mechanism model

Determination of dynamic loads of the considered model of crank mechanism and hence the other basic engine parts, primarily a block and a cylinder head, are related to the determination of the kinematics of this system.

The diagram of the crank mechanism model is shown in figure 1, which also represents the following engine parts: O - crankshaft, A - crank pin, I - crank moment of inertia, B - piston pin, M - piston mass. Additionally, the following symbols describing the model configuration were introduced: r - the crank length (distance between the crankshaft and crank pin axes), l_0 - the connecting rod length (distance between the crank pin and piston pin axes), φ - crank rotation angle. The piston displacement and velocity for any crank rotation angle φ can be determined on the basis of mechanism configuration presented in figure 1. Determination formulas given for the piston displacement and velocity are presented respectively in equation (1) and (2).

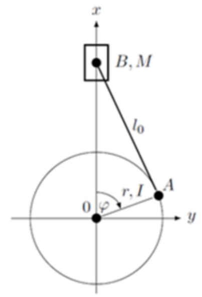

Figure 1. The scheme of the crank mechanism model Short description of figure.

$$x = r\cos(\varphi) + \sqrt{-r^2\sin^2(\varphi) + (l_o + u)^2} \tag{1}$$

$$\dot{x} = -r\sin(\varphi)\,\dot{\varphi} + \frac{-r^2\sin(\varphi)\cos(\varphi)\,\dot{\varphi} + (l_o + u)\,\dot{u}}{\sqrt{-r^2\sin^2(\varphi) + (l_o + u)^2}} \tag{2}$$

Kinematic analysis of mechanisms is used to study motion and is an integral element of investigating the causes of existing motions that dynamics deals with. The dynamic analysis takes into account external forces, inertia forces, gravity forces and the force moments acting on the elements of the mechanism.

The kinetic energy was determined as the sum of the energy of the system mass of connecting rod l_0 and inertia moment of the crank r. The potential energy in the discussed system results from the elastic properties of the connecting rod l_0.

Hence, the Lagrangian (3) represents the total energy of the system under consideration presented in figure 1. The equation describing L is given in (3):

$$L = \frac{1}{2}I\dot{\varphi}^2 + \frac{1}{2}M\dot{x}^2 - \frac{k\left(r\cos(\varphi) + \sqrt{-r^2\sin^2(\varphi) + (l_o + u)^2} - l_o\right)^2}{2} \tag{3}$$

Nonholonomic model forces acting on the particular crank are caused by the other parts of a crankshaft, the entire powertrain or gas forces, which are the reason for stable operation of the engine. Thermodynamic force is the result of phenomenon connected with the particular stroke and instantaneous volume of the cylinder during operation. Depending on the assumed cycle, there is another thermodynamic transformation for the particular working stage. It states the relationship between the current value of the piston volume and the working pressure. After complex rearrangement of the formulas it is possible to determine an equation which relates the piston motion and the system pressure.

The considered engine load - Otto cycle is presented in figure 2 and has the following form:

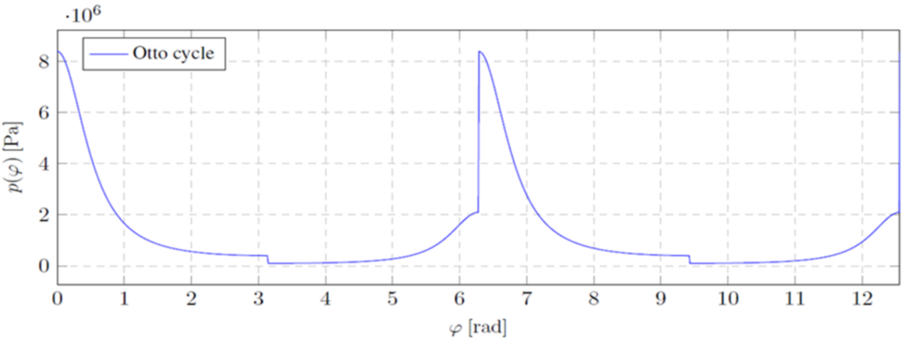

Figure 2. Otto cycle.

The assumed engine cycle describes particular stages of the engine operation. It assumes an infinite fast combustion and a process of temperature increasing. Moreover, it was adopted that compression and working cycle do not consider heat transfer (governed by an adiabatic transformation). Intake and exhaust strokes are given by an isobaric transformation with the atmospheric pressure.

3. Description of the engine under investigation

The considerations concern the TwinAir engine, which is a straight-twin type of an engine designed by Fiat Powertrain Technologies. The engine has hydraulically actuated variable valve timing and lift technology. It is offered in naturally aspirated and turbocharged variants. The TwinAir is popular for its reduced size, weight, fuel consumption and CO_2 emissions.

The considerations concern the Fiat TwinAir engine since the author participated in the industrial research projects aimed at the process of redesigning a diesel engine vibration absorber [4], [5]. The engine body, head and crankshaft were provided in order to examine torsional vibration dampers on a built test stand. Having the engine geometrical parameters and mechanical properties enabled numerical analyses simulating real processes of combustion considering thermodynamic parameters of the Fiat TwinAir combustion chamber. On this basis the engine load was obtained by numerical computations.

The engine is characterized by the geometrical parameters and mechanical properties presented respectively in table 1 and 2.

Table 1. Fiat TwinAir - geometrical parameters.

TwinAir engine geometrical parameters	
Geometrical parameter	**Naturally aspirated**
Displacement	1.0l (964cm^3)
Cylinder bore	83.5mm (3.29in)
Piston stroke	88mm (3.5in)

Table 2. Fiat TwinAir - mechanical properties.

TwinAir engine mechanical properties	
Mechanical properties	**Naturally aspirated**
Power output	60PS (44kW)
Torque output	88Nm at 3500min^{-1}
Compression ratio	11.2:1

The information in tables 1 and 2 show that the object under investigation is a small engine with high operational properties. It indicates different dynamics of the device than for the older industrial solutions. Practical observations present the demand of the additional equipment to control the object dynamics and the most efficient tools for the design calculations. That causes a need for more detailed modelling of the engine, especially in the field of a transdisciplinary engineering.

4. Numerical simulations

In order to study the proposed dynamic coupled model, the authors performed some numerical simulations allowing for reliable evaluation of the modelling based on a transdisciplinary approach.

The plot depicted in figure 3 presents a crank displacement being influenced by the system's flexible properties. The linear curve was introduced for comparative purposes and shows the dynamic response of the uncoupled system where its rigidity was not included in the considerations. It can be stated that despite the small impact on dynamics in quantitative terms, qualitative changes in the dynamic response of the system can be captured. By analysing the oscillatory nature of the crank displacement, it can be concluded that the system equivalent stiffness is affected not only by the elastic properties of the gas force, having relatively less impact on the system dynamics, but mostly by the crank system stiffness taken into consideration. This indicates the importance of considerations of mutual relations between the thermodynamic and mechanical system properties as the latter are often omitted in the engine modelling process.

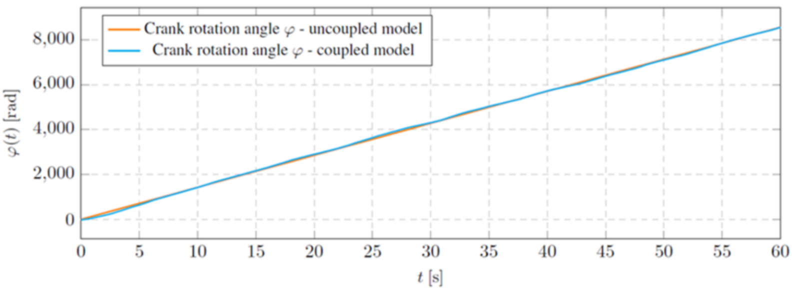

Figure 3. Crank rotation angle.

More significant qualitative and quantitative changes can be seen on the crank rotational speed plot presented in figure 4. The rotational speed oscillation is stable but not periodic. The results of simulations reveal a stochastic character of the engine dynamics. The phenomenon is compatible with empirical observations, which are uncorrelated and have random properties.

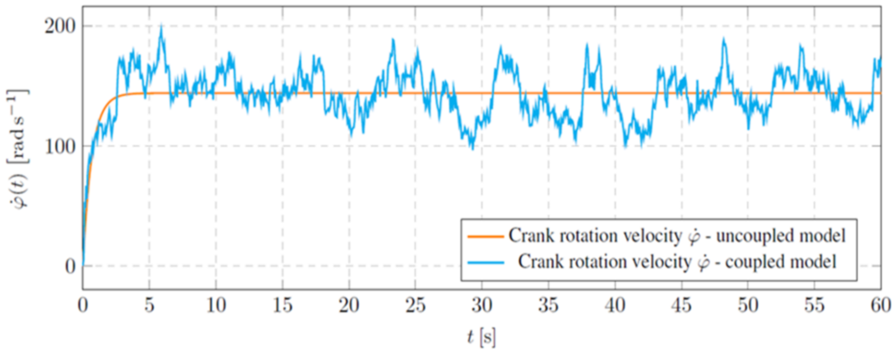

Figure 4. Crank angular velocity.

It can be stated that the obtained numerical simulations depict significant difference between an uncoupled mechanical approach and transdisciplinary modelling. The evaluated values have similar integral properties as a mean value or an average slope and very different dynamic features as a signal velocity or Root Mean Square (RMS) value.

Figure 5 depicts plots of gas forces considered in a modelling process of the engine dynamics. Gas forces computed based on the coupled (thermodynamic) and uncoupled (kinematic) model are presented and discussed as they reveal strong qualitative differences resulting in a different system dynamic response. The blue waveform represents a case of a kinematic-based engine load (due to displacements based on the uncoupled model) while the orange one stands for a fully dynamic gas force implementation (computed with the coupled model). Based on a comparative analysis, a repetitive, cyclic load in case of kinematically simulated gas force can be easily observed, while the changes of a dynamic engine load is a unique process related to the combustion process of the air-fuel mixture, which is never repeatable.

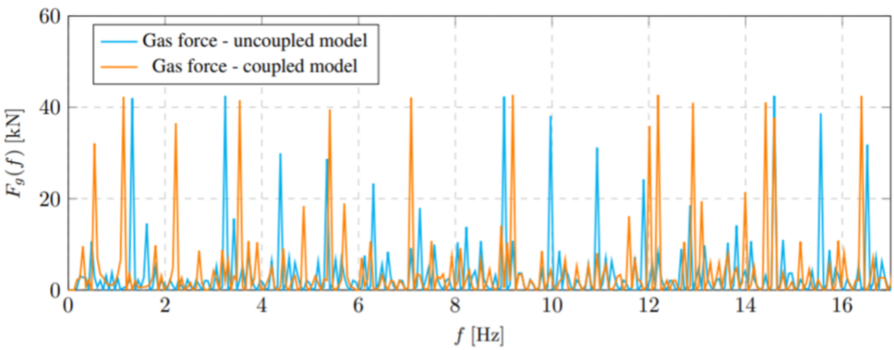

Figure 5. Gas force - comparative results.

Non-periodical characters of transdisciplinary modelling results indicate the essential difference between the two types of numerical models' simulations. That leads to conclude the proposed model better represents an irregular character engine operation. Moreover, it can be stated that a random character of the subsequent working cycles can also be caused by the irregularity of the system velocity, not only by a stochastic process of combustion.

5. Conclusions

It can be concluded that the application of transdisciplinary engineering enables qualitatively new results which differ significantly from the results of a typical kinematic analysis of a combustion process in a reciprocating engine. On one hand, simulations which were carried out have similar general properties to the simpler models, especially in the area of the integral properties as a mean value or an average power. On the other hand, they are characterised by very different system dynamics, which reflects in a relatively high irregularity of the instantaneous value of the angular velocity. Comparatively to commonly utilised models, the performed analysis of the proposed uncoupled model delivers results which are closer to real engine dynamic behaviour.

The industrial research project creates a need of simple computational model of the engine for design processes of the Torsional Vibration Damper being Dynamic Vibration Absorber. Considering an operational principle of this kind of damper, the designed device has to be tuned to the power unit properties. Despite the model of simple double degree of freedom rotor was enough for this purpose, a determination of the excitation (caused by thermodynamic cycle) had to be supported by more sophisticated model. Articles and reports regarding the investigation present efficiency of sophisticated models in case of solving industrial problems [6, 14]. Transdisciplinary modelling of the engine operation enables to obtain relevantly better results as shown in the paper. Such an approach is necessary in order to select proper parameters of the designed device especially in case of the simultaneous fulfilling operational (expected engine dynamics) and functional conditions (desired inertial and geometrical parameters).

The carried out investigation presented in the subsequent sections of the paper allows for the formulation of the following conclusions:

1. As modern spark ignition engines become lighter, more efficient and more loaded than commonly used units, it results in different dynamics of the entire powertrain and also creates the demand for a more accurate model for the purposes of engine design, equipment selection and powertrain control. The transdisciplinary engineering approach enables the preparation of a tool that meets the above requirements.

2. The model proposed by the authors takes into account more details of crank system stiffness, gas force elasticity, viscous and inertial properties and enables the investigation of their mutual relationships. It results in a complex but solvable problem. The obtained result expands on models known in literature but keeps all the properties of simpler models.

3. The results of the performed investigation present complex dynamics of the engine outputs as an angular displacement or velocity. It is strictly connected with nonlinear features of the proposed coupled model. The authors assumed that excitation in the form of a gas force generated in the combustion process depends not only on time but also on state variables. It results in a nonlinear system with extremely different dynamic properties. From the vibrational point of view, it is a selfexcited system characterised by the limit cycle which is the same operational velocity of the engine.

The proposed approach can be used to offer results qualitatively compatible with existing engines but there are some areas where even better results can be obtained. Some weakness of the presented method is the simplified model of the gas force. This will lead to some discrepancies when comparing to experimental data but still external outputs of the engine model are close to reality which brings the conclusion that even the proposed simplified methodology can be used successfully.

This transdisciplinary modelling approach might contribute in process of engines design being upgraded in terms of technical level what constitutes the added value resulting from a merge of two disciplines thermodynamics and mechanics of machines.

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Product and Process Development

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Design Entropy Theory: A Novel Transdisciplinary Design Methodology for Smart PSS Development

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Abstract. Smart product-service systems (Smart PSS), as an emerging transdisciplinary paradigm, leverages smart, connected products (SCPs) and their generated services as a solution bundle to meet individual customer needs across different engineering fields. Owing to the advanced information and communication technologies, Smart PSS development differs from the existing product and/or service design mainly in three aspects: 1) closed-loop design/redesign iteration; 2) value co-creation in the context; and 3) design with context-awareness. These unique characteristics bring up new engineering design challenges, and to the authors' best knowledge, none of the existing design theories can address them well. Aiming to fill this gap, a novel design entroy theory is proposed by adapting the information theory with engineering design. In this context, Smart PSS can be regarded as the information container. Hence, the closed-loop design/redesign iteration can be treated as the dynamic change of information and entropy in a balanced system. Meanwhile, the value co-creation process is considered as the exchange of accumulated information via the container. Lastly, the design context-awareness represents the process of eliminating entropy. As a novel prescriptive design theory, it follows Shannon's information theory to determine the best solutions by considering the three characteristics integrally. It is envisioned this appraoch can largely facilitate today's industrial companies' digital servitization towards Industry 4.0 with better performance and user satisfaction.

Keywords. Design theory, smart product-service systems, information theory, design entropy

1. Introduction

In the context of industry 4.0, the current digital technologies, including Internet-of-Things (IoT), cloud/edge computing, and Big Data analytics have enabled the industrial digital transformation towards digital servitization [1]. This IT-driven value proposition paradigm is named smart product-service systems (Smart PSS) [2][3], where smart, connected products (SCPs) and their generated advanced services are delivered by the service provider/manufacturer as a solution bundle to be adopted in many disciplines.

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Unlike other types of PSS paradigms, Smart PSS considers both the online smartness of cyberspac, and offline smartness of the physical space with sustainability concerns [4].

Nevertheless, as an emerging paradigm, none of the existing design methodologies emphasizes its multidisciplinary essence, as a sociotechnical system. Meanwhile, scarcely any work provides a fundamental approach to realize Smart PSS design by considering its transdisciplinary design characteristics (i.e., value co-creation, closed-loop design, context-awareness). Aiming to fill in the gap, this research work, as the first attempt, proposes a novel design methodology for the Smart PSS development, which combines the two disciplines of engineering design and information theory. The rest of this paper is organized as follows: Section 2 presents the unique design characteristics of Smart PSS and their existing works. Section 3 provides a comprehensive review of information design and entropy in information theory. Section 4 defines design entropy theory, discusses the concept of design entropy and conversion ability, explains its design process, and introduces some formulas for the quantitative measurement of design entropy. Section 5 illustrates the concepts with examples. The conclusion and future work are summarized in Section 6 at last.

2. Smart PSS design characteristics

Based on the transdisciplinary nature of Smart PSS, three unique design characteristics of Smart PSS are outlined below.

Value co-creation is carried out by stakeholders who are mainly classified into three species, i.e., users, service providers, and manufacturers/vendors [5]. User participation is the most crucial part of the innovation process (e.g. user experience-driven innovation), which ensuring the real-time interaction between designers and users is fundamental to the development of Smart PSS.

Closed-loop design is conducted among SCPs and e-services, which can generate, collect, process and exchange relevant information through the system lifecycle, especially during the usage stage. Based on the useful information of the Smart PSS, the closed-loop design emphasizes the integration of innovative design and iterative design processes into the development thereby assisting the designers and engineers efficiently completing not only the creation from scratch but also the real-time upgrade/modifications.

Context-awareness is based on those intelligent systems [4]. With advanced sensors and inductive technologies provided by the intelligent systems, context-awareness can enable Smart PSS to deeply understand their customers, including their behavior, motivation and requirements. Therefore, Smart PSS involves a novel methodology which can distinguish certain contexts accurately and update solutions adaptively.

Nowadays, none of the existing methodologies which always adopted in PSS development can meet all the three characteristics. One can find that it still lacks a transdisciplinary design approach for Smart PSS. Aiming to fill this gap, a novel transdisciplinary methodology by combining two disciplines of engineering design and information theory will be proposed to solve the challenges of Smart PSS's unique characteristics in this paper.

3. Fundamentals of design entropy theory

3.1 Information design

Information as an existence independent of material and energy [6] has a transformation relationship with data and knowledge. The researches on the information of product/service can be summarized as: (1) how to mine information as a value from user-generated data and transfer it to users [7][8], and (2) how to manage the information generated by designers during product/service development [9][10]. The researches on the information of PSS can be basically classified into two categories, including (1) the concept of information modules can be proposed and used as a core module [11][12]to replace the product and service modules [13], and (2) an information system can be established to record and update the input and output information of each module under different contexts for completing and selecting the solutions more accurately [14].

3.2 Entropy

Shannon (1948) [15] systematically discussed the fundamental issues of information communication by using mathematical tools (e.g., probability theory and statistics) to propose the quantitative expression of information, the calculation of transmission rate, the calculation of channel capacity, and the coding theorems of information transmission. Menhorn et al. (2011) [16] presented design entropy as a measurement for the complexity of a given circuit by resorting to Shannon's information theory, which is mainly used in the digital circuits field rather than the design field. Based on the entropy in information theory, Wu et al. (2016) [17] defined design entropy as a description of the disorder found in design objects and proposed a design entropy model, which is a measurement of the degree of information chaos in a user interface. Since most design problems of Smart PSS need to extract and summarize information in the context, which cannot be solved effeciently by the existing design entropy methods.

It should be noted that, Axiomatic Design also adopts the information theory [18] to determine the probability distribution of the system range and the common range to compute the system information content. Nevertheless, it only considers the mapping process of the pre-defined product domains for solution evalution. Both the in-context product-service information and the conversion capabilities are ignored.

4. Design Entropy Theory

4.1 Introduction of Design entropy theory

Due to the intelligentization, digitization and servitization characteristics of Smart PSS, it should take information stored and transmitted in the system as the research objective, instead of physical substance. As depicted in Figure 1, when the Smart PSS reaches the end of lifecycle, the physical substance will be disposed, and only its parts and materials can be reused and recycled. However, information which largely differs from the physical substances can be transmitted to the new Smart PSS completely.

From an informational perspective, design entropy theory regards Smart PSS as the carriers of information, and the design process as the conversion from the information to physical products or services. It is favorable to the establishment of a Smart PSS ecosystem by considering a series of interconnected systems, not a merely single system. The information in smart PSS can be input by designers, engineers, and other stakeholders directly. Meanwhile, it also can be extracted from the environment data collected by SCP sensors, the behavior data generated by customers in using period, and the online data of social networks.

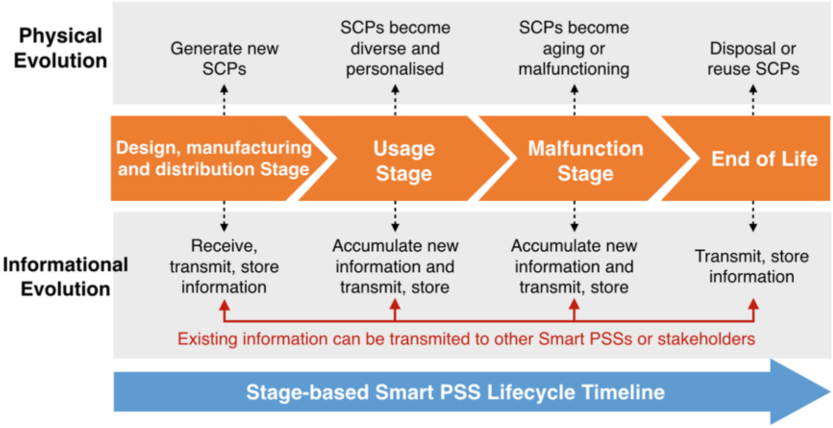

Figure 1. Physical and Informatic evolution in Smart PSS lifecycle.

4.2 Design entropy

Before proposing the definition of design entropy, the scope of information in Smart PSS needs to be explained. Information in Smart PSS is defined as the descriptive information which describes the status of the stakeholders, SCPs, services, and environment, and introduces the solutions. Meanwhile, design plan of Smart PSS differs from the traditional nomenclature, which is a description (blueprint or CAD model) of the Smart PSS. It mainly consists of three parts, including the SCP design plan (usually displayed as a CAD model), service design plan (usually displayed as a service blueprint), and conversion plan that will be mentioned in Section 4.5.

Design entropy could be a measure of information design in Smart PSS for describing its certainty degree. The absolute value of design entropy is positively correlated with the uncertainty of systems. If system certainty is higher, it will cause design entropy to be lower, the accuracy of its context awareness to be higher, quality of real-time iterative design based on the current context to be better, and user participation and satisfaction degree to be higher. Therefore, Design entropy theory needs to dynamically reduce the design entropy for maintaining the highest certainty of the system and ensuring the most exceptional adaptability for each context during usage stage.

To calculating design entropy, we define a new measure called *Conversion ability*, which is denoted by C. Conversion ability represents the ability to convert the information, which is denoted by x_i into the information, which is denoted by x'. If the conversion ability of Smart PSS is higher, its conversion effect from x to x' to be better and design entropy of this system to be lower.

Let the design entropy of a system be represented by D; the value of D is evaluated:

$$D = -logC \tag{1}$$

, where $0 \leq C \leq 1$, and all $D \geq 0$. Thus if the conversion ability of a system is the highest, the value of C is 1, then $D = 0$. On the contrary, the value of C is 0, then $D = +\infty$. In order to compare the value of design entropy in different contexts and systems, the same logarithmic base 2 is used in each equation of design entropy. Furthermore, the total design entropy of a system is given by

$$D_{total} = D_{innovative} + D_{iterative} \tag{2}$$

, where $D_{innovative}$ is innovative design entropy of the system, and $D_{iterative}$ is iterative design entropy. The former one means the design entropy in the innovative design stage of creating a new Smart PSS. Moreover, the latter one means the design entropy in the iterative design stage, when redesigning, modifying, or enhancing the solutions according to the new information collected from sensors during use.

4.3 Innovative design entropy and innovative conversion ability

The innovative design entropy of a system is defined as $D_{innovative}$, according to the innovative conversion of the system, $C_{innovative}$:

$$D_{innovative} = -log C_{innovative} \tag{3}$$

This quantity measures how uncertain we are of the system in its innovative design stage when we know $C_{innovative}$. $C_{innovative}$ refers to the conversion ability in the design plan so that this design can effectively convert information in usage stages. $C_{innovative}$ is further denoted as:

$$C_{innovative} = A_1 \times Y_1 + A_2 \times Y_2 + \cdots + A_n \times Y_n \tag{4}$$

, where Y_n is a parameter that represents the ability that, design plan can convert information in a specific way when the design is used in the future. Since $0 \leq C \leq 1$, we let $0 \leq Y_n \leq 1$. Different research objects have different parameters. The matching degree with user requirements, adaptability measure, and the number of sensors are utilized according to the unique characteristics of Smart PSS proposed. After the normalization processing, these three parameters are used as Y_1, Y_2, Y_3. Furthermore, coefficient A_n is the weighting factor introduced because the importance of Y_n is different in each case. A_n is given by the stakeholders for expressing the importance of Y_n to the system. Thus $0 \leq C_{innovative} \leq 1$ and $0 \leq Y_n \leq 1$, where

$$A_1 + A_2 + \cdots + A_n = 1 \tag{5}$$

4.4 Iterative design entropy and iterative conversion ability

Figure 2 illustrates the process of information conversion in the usage stage of Smart PSS. After collecting new information, Smart PSS builds and updates the usage context according to this novel one. In a specific usage scenario, Smart PSS should firstly determine whether the information is noise, which refers to the useless information for design in the current context, and delete it if the information is noise. If it is not noise, this information x should convert into the information x'. After this processing step, the information should be stored or deleted.

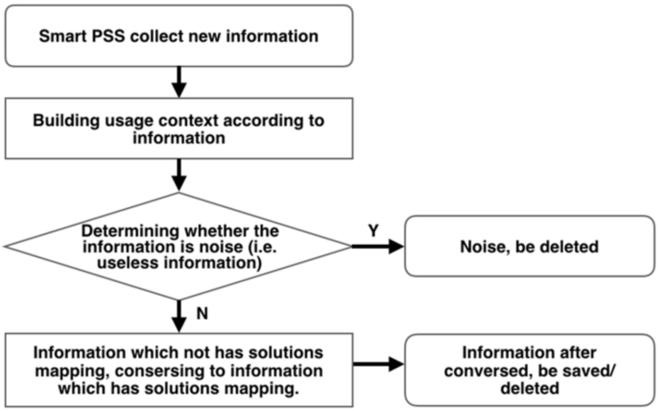

Figure 2. Process of information conversion in usage stage.

Iterative design entropy consists of the sum of the design entropy of all non-noisy and unconverted information x, which is collected by the system during the use phase as:

$$D_{iterative} = \sum_{x \in \mathcal{X}} D(x) \tag{6}$$

, where $\mathcal{X}$ is the set of all non-noisy and unconverted information collected by the system, and information x belongs to the set $\mathcal{X}$. The information x_i converted into m pieces of information x' (i.e., $x_1{}'$ to $x_m{}'$), through m items of channels. The design entropy of information x_i is

$$D(x_i) = -\sum_{m \in \mathcal{M}} W(x_i)\ _m \, logC(x_i)_m \tag{7}$$

, where $W(x_i)\ _m$ is the weighting factor of channel m, representing the correlation of information x_i and $x_m{}'$. $W(x_i)\ _m$, which is modified in a diverse context, is given by the stakeholders. $\mathcal{M}$ is the set of all channels between information x_i and information after conversion, and channel m belongs to the set $\mathcal{M}$. $C(x_i)_m$ refers to the conversion ability to convert information x_i into $x_m{}'$ through channel m, representing the single-channel conversion capability for a single piece of information in the system.

$$C(x_i)_{\mathrm{m}} = A(x_i)_{\mathrm{m}_1} \times Y(x_i)_{\mathrm{m}_1} + A(x_i)_{\mathrm{m}_2} \times Y(x_i)_{\mathrm{m}_2} + \cdots + A(x_i)_{\mathrm{m}_n} \times Y(x_i)_{\mathrm{m}_n} \tag{8}$$

, where $Y(x_i)_{\mathrm{m}_n}$ is a parameter that represents the ability that, information x_i can convert into information $x_m{}'$ in a specific way efficiently and accurately. Different information conversion types have different parameters. The user satisfaction degree, time and cost of completing information conversion are utilized according to the unique characteristics of Smart PSS proposed. After the normalization processing, these three parameters are used as $Y(x_i)_{\mathrm{m}_1}$, $Y(x_i)_{\mathrm{m}_2}$, $Y(x_i)_{\mathrm{m}_3}$. Coefficient $A(x)_{\mathrm{m}_n}$, which is given by the stakeholders, refers to the weighting factor of the importance of $Y(x_i)_{\mathrm{m}_n}$.

4.5 Design process of Design entropy theory

Figure 3 shows the design process by using design entropy theory. In the innovative design phase, a design plan needs to be proposed, and the innovative design entropy of the plan need to be calculated. The entropy should be reduced as possible, and the plan with the lowest design entropy should be selected. In the conversion plan, it is necessary to predict and list information x, which will be collected in future stages, and design its conversion plan and converted information x'. After manufacturing, Smart PSS will be used by customers. Collecting new information continuously during the usage stage makes iterative design entropy increase. Therefore, Smart PSS needs to convert the information in real-time to reduce the design entropy.

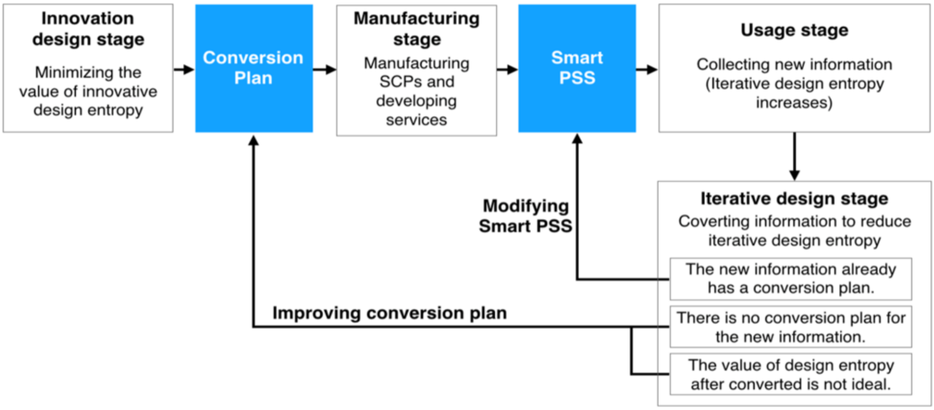

Figure 3. Design process of design entropy theory.

5. Case Study

Empirical case studies have proved as effective model verification methods [7][23]. Hereby, this section provides a case study of smart travel assistant product-service system to verify the effectiveness of the proposed design entropy theory. Smart assistants (e.g. service robot, navigation APP) have been increasingly introduced in recent years. Elderly users always live in the local retirement homes, so that they need it to address their traveling requirements, such as: sending the health status of elderly to their relatives in real-time, and assisting elderly in choosing and visiting the tourism destination.

Step 1: Select the design plan with the lowest innovative design entropy. Figure 4 shows the prototypes of the smart travel assistant design plans, and their innovative design entropy. After calculating and comparing, plan 1 with the lowest innovative design entropy should be selected for subsequent development.

Step 2: Predict and list the information to be collected in different usage contexts. As shown in Figure 4, the information of the smart travel assistant is summarized from three primary contexts of the elderly users' usage.

Step 3: Planning the information x_m' after conversion.

Figure 4 shows the preliminary conversion plan of the smart travel assistant. At this stage, the developers should analyze information x_i holistically and give the corresponding information x_m' after conversion. The developers need to conceive of the conversion plan by combining the design plan and the requirements of stakeholders.

Step 4: Mark weighting factor $W(x_i)_m$ and output information conversion plan. Figure 4 shows the information conversion plan of the smart travel assistant. The conversion plan should be completed before SCPs manufacture and service development. The conversion plan will be continuously adapted and iterated during usage.

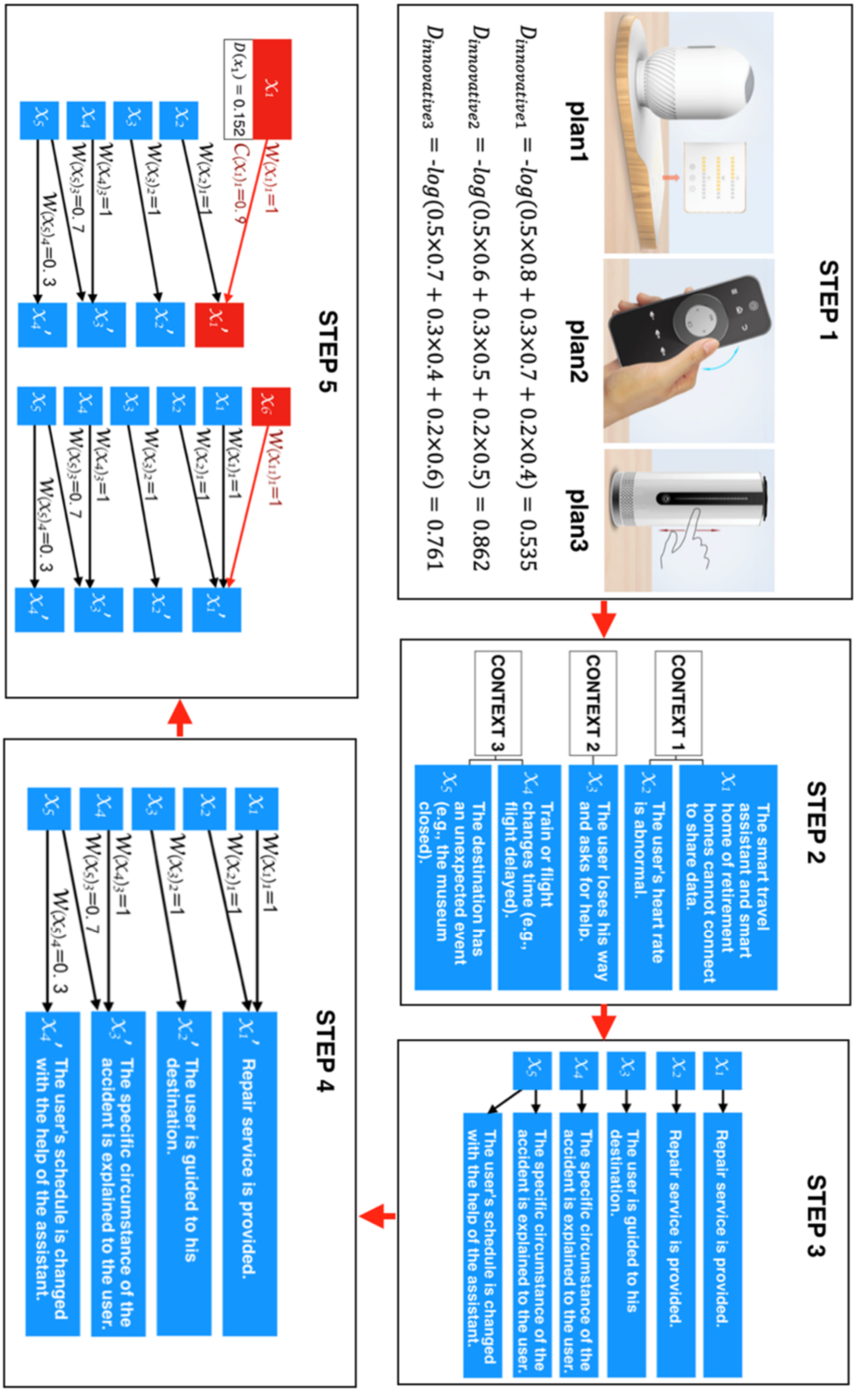

Figure 4. Design process of the smart travel assistant with design entropy theory.

Step 5: Execute or iterate the conversion plan during customers usage phase. The value of iterative design entropy needs to be monitored in real-time during the usage stage to enable that the value is as expected: 1) If the newly collected information was predicted in a conversion plan before, the conversion channel of this information can be activated directly, and the system should provide services, adjust parameters, or replace modules according to the corresponding information x_m'. The conversion ability can be calculated and recorded by obtaining the user satisfaction degree, time, and cost of completing information conversion (Figure 4). 2) If the newly collected information has not been predicted before, the design entropy of this information will tend to infinity. The system should modify the conversion plan, including converting the information x_6' to an existing information x_1', or converting it to a new information x_6'.

6. Conclusion and future works

Smart PSS, as an emerging IT-driven transdisciplinary paradigm coined in 2014, has attracted ever-increasing attention among academics recently. Nevertheless, there still lacks a fundamental design methodology for Smart PSS development. To bridge this gap, this paper presents a novel design entropy approach that focuses on developing Smart PSS by combining the two disciplines of engineering design and information theory. It depicts the fundamental mechanism of the design literation process in the Smart PSS. Moreover, it also provides insightful potentials for complex sociotechnical systems to quickly satisfy customer requirements in a context-aware manner. As an explorative theorectical study, future work can also be done in the following aspects:

1) *Automatically monitoring the value of the design entropy.* Automatic supervision will help designers only modify the plan when the design entropy does not meet the standards, instead of keeping observing the value of design entropy, which could contribute to higher productivity through transdisciplinary engineering.

2) *Building a general platform for conversion plan*: A general platform for conversion plan can be built to collect conversion plans from different Smart PSS, which need intensive collaboration across different disciplines.

It is envisioned this appraoch can largely facilitate today's industrial companies' digital servitization towards Industry 4.0 with better performance and user satisfaction.

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Evaluation and Development of Digital Collaboration Techniques for Interdisciplinary Collaboration

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Abstract. In innovative industrial companies, collaboration techniques and laboratories have been in use for years. What historically started with teleconferencing instead of business trips has now reached the status of normal tools for interdisciplinary cooperation in these companies with advances in technologies such as PCs and data broadband as well as software such as Computer Aided Design (CAD), Virtual Reality (VR) and Augmented Reality (AR). But the collaboration techniques are often installed in extra rooms, e.g. video conferencing facilities and large VR laboratories. Other technologies such as chat programs can be used by any employee directly at his workplace. Without the use of these techniques, the short development times required today in many industrial sectors cannot be achieved and even remote maintenance of machines at the customer's would be impossible for machine manufacturers. Within a research project, digital collaboration techniques are inspected and evaluated regarding their suitability for interdisciplinary cooperation in various applications. Collaboration techniques include special hardware for graphic simulations and head-mounted displays for 360° visualization of digital objects. Additionally different software for cooperation with graphics, video and conference programs distributed over several locations is tested, evaluated and partly newly developed. The application cases are processes from engineering and for planning of buildings. Based on the requirements determined during the tests, a new user-friendly mobile collaboration environment was developed. This collaboration environment integrates the different technologies of graphic simulation as well as already established methods such as video transmission or video conferencing and chat programs in a suitcase system.

Keywords. Digital Collaboration, Matrix Network, Mixed Reality, Remote Maintenance

Introduction

These days, the working environment is changing quickly, driven by globalization, outsourcing and cooperation within networks. For employees, this means that they have to face an increasing interdisciplinary collaboration of teams around the world. Especially knowledge work requires an effective communication and collaboration to ensure the exchange of information and knowledge. Nowadays, the exchange of

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information and documents between persons is largely handled via electronic communication and information media, which leads to new challenges concerning not only interdisciplinary communication, but also intercultural communication based on language barriers etc. Conventional collaboration tools like e-mail or videoconference are no longer sufficient, because it is often difficult to explain complex technical content to someone who has a different professional background and possibly also another native language. With the help of modern colaboration tools including graphical simulation, it should become easier to communicate and therefore the productivity of virtual meetings will increase. Meanwhile, there is a wide spectrum of different sorts of collaboration tools, that are supposed to adress these challenges. However, there is no real structure or categorization for digital collaboration tools in the literature.

Firstly, this paper aims to categorize the common tools for digital collaboration and develop a mobile collaboration environment. This environment is an all-in-one device which is suitable for almost every purpose and serves the thin line between offering as many functions as possible and offering a convenient mobility. It addresses the problem that in many cases, especially in the AR/VR field, the corresponding technologies are not available in every office, laboratory or meeting room. The new developed collaboration environment can be conveniently moved into the appropriate room and started up in just a few simple steps. With the help of this, the times with disorder of many unsorted cables at workplace or in meeting rooms (as seen in Figure 1) are over.

Figure 1. Mess of cables seen on a workshop in Stuttgart and a VR-Laboratory.

If in a collaboration project a large amounts of confidential data must be shared through the internet, the issue of IT Security is gaining in importance as well. Concerning this matter, this paper introducing the Matrix Network as one possible solution. In another chapter an example for collaboration with digital tools the use of Mixed Reality in the field of remote maintenance is given.

1. Methods and technics for digital collaboration

A study from the McKinsey Institute has confirmed, that online collaboration tools can improve the employee's productiveness up to 20-25%. [1]

There is a large number of software solutions for digital collaboration but there is no real categorization or struturce in literature so far. The fast moving nature of the IT field makes this further complicated by the fact that the new software solutions or plugins are created or published almost on a daily basis.

The website *www.capterra.com* provides an initial overview of all kinds of software solutions on the market. The search for collaboration related software categories is summarized in Table 1.

Table 1. Results of the search for keywords in *www.capterra.com* (status: March 2019) [2].

Software Categories	Number of Software Solutions
Collaboration Software	544
Meeting Software	153
Web Conferencing Software	134
Social Network Software	106
Team Communication Software	66
Internal Communication Software	53
Unified Communications Software	43
Employee Communication Tools	29
Cloud Communication Platform	25

Multiple nominations of the same software were possible. There are even more similar Software Categories with numerous solutions. On the one hand, this shows that there must be a great demand for such tools. But on the other hand, it also shows that users are faced with a confusing flood of solutions and it is difficult to select the right product according to the respective individual requirements.

However, the above categories do not say anything about the technique being used. By a more detailed examination, these technique can be divided into the following categories:

- Instant messaging
- Voice and video conferencing
- File sharing
- Screen sharing
- Document collaboration
- Knowledge center
- Internal social network tools
- Project management tools
- AR/VR-collaboration

2. Use cases and their requirements for collaboration

The requirements for the mobile collaboration environment in this paper are based on the four current use cases from the research project ´Entwicklung einer mobilen Kollaborationsumgebung EMOKO´ at the Albstadt-Sigmaringen University.

The first use case (UC 1) is the industry 4.0 demonstrator in the machine hall of the University in Albstadt. This cyber physical system (CPS) consists of industrial robots, conveyors, storage systems and an automated guided vehicle system (AGV). This assembly cell serves to teach students the contents and technologies of industry 4.0. The mobile collaboration environment is supposed to support the interdisciplinary involved persons during the commissioning process using VR/AR Simulations and to stream the content directly to the lecture hall or to the internet.

The second use case (UC 2) is in the BIM (Building Information Modeling) sector. The UC 2 evaluates especially the planning of big commercial kitchens, a special field of expertise of one of the professors involved in the research project. Commonly, non-specialists have their difficulties by reading und understanding construction plans and design drawings. By using construction specific Virtual and Augmented Reality software, even laypersons should be able to examine and compare the different offers during the bidding phase regarding the food preparation process in a commercial kitchen.

In use case 3 (UC 3), the ´laboratory for digitalization in the food industry´ is looking for a remote maintenance solution by using VR/AR Tools. It is the objective to evaluate the use of VR and AR technologies to guide a machine operator throughout a repair or maintenance process by getting advice from an expert located somewhere else.

Use case 4 (UC 4) is settled in the research project ´Digitaler Produktlebenszyklus DiP´ (information: http://dip.reutlingen-university.de). The collaboration environment here is supposed to improve the communication between the participating scientists from different universities. It solves the communication problems, particularly in the event of technical problems during the virtual commissioning process with graphical simulation.

After a more detailed analysis of these four use cases, their requirements for collaboration tools can be categorized in:

- Instant messaging
- Audio and video conferencing
- Video recording
- Standard presentation technology
- Remote software
- AR/VR (especially with Head Mounted Displays)

3. Requirements towards a mobile collaboration environment

In addition to these specific requirements in the use cases, there are several requirements regarding to the mobility of the collaboration environment as well. These general requirements are:

- Good handling regarding the size and weight (transportable suitcase; should fit into the trunk of a standard car)
- Simple set up and commissioning
- Few outside cables to connect
- Low maintenance
- Cost-effective
- Sustainability (selected hardware and software should still be useable in two or more years)

The development of a new mobile collaboration environment is based on the combined requirements from the four use cases and other general requirements [3]. For the development process of the colaboration rack IT experts colaborate with mechanical designers to create a solution that provides all the Software and Hardware for the colaboration and also make the rack easy to handle and move to different locations. The developed product is a mobile rack solution, divided into three levels. These levels contain a high-end computer, a slide with convenient foam inlays for the HTC Vive and the associated accessories and on the top of the rack is a sound box and a inclinable touchscreen monitor which are covered with a removable top cover (as seen in Figure 2). In case of need the foam inlay for the Head Mounted Display (HMD) can easily be replaced with an inlay for other HMD's like the Oculus Rift or the Meta-2. For an effortless transport in a normal car, the rack can be dismantled into three individual boxes.

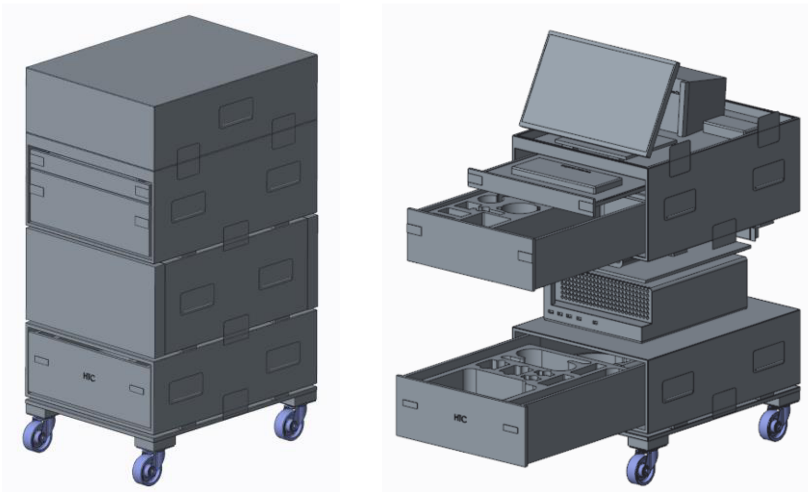

Figure 2. CAD construction of the mobile collaboration environment.

4. IT Security in collaboration

Especially when working together in an industrial or research context, there is always some sensitive or confidential information and documents that need to be exchanged. For this purpose, the structure of the IT tool ´Matrix Network´ (https://matrix.org/) has turned out to be very useful for a secure communication. It is an open standard for interoperable, decentralized, real-time communication over IP and offers an end-to-end encryption.

To make use of the ´Matrix Network´, there are several clients available, based on different programming languages. The Riot Client is the one which offers the most functionality. It works on the common operating systems like Windows, Linux and Mac. There is a desktop and a web application and Riot is even available on Android and iOS. It provides voice and video calls and conferences on all platforms. And most importantly, Riot supports end-to-end encryption which can be chosen to be activate for each individual chat. [4] Another advantage compared to many other software products is that there are no license or server costs or other limitations.

For this reasons, the Riot Client is the Standard-Client of choice for the University Albstadt-Sigmaringen, but if cooperating Universitys or Companies require different Software for communication, those can be added, too. Figure 3 shows the IT structure of a network with three universities as an example.

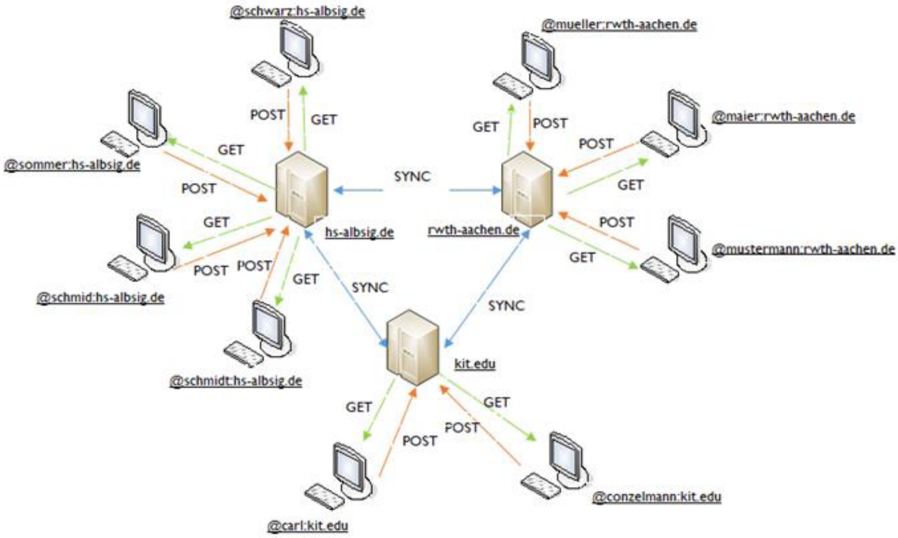

Figure 3. Decentralized structure of the Matrix Network.

5. Application for the use of Mixed Reality in remote maintenance

Nowadays, experts and high-skilled mechanics travel around the world from one location to the next location. This is time consuming, high costing and also brings physical and mental stress for the traveler. The use of instructional videos with Mixed Reality can produce relief. The expert can stay at his office and record step-by-step video guides on a virtual twin of the machine in a greenbox and make this instruction available for the machine operator at the location of the occurring problem.

As an industrial application example, the VR-Software CMC ViewR® is used in combination with the Open Broadcaster Software (OBS) [5]. The ViewR Software creates two virtual video signals from the same point of view (foreground and background). These virtual cameras must be positioned at the same position as the real life recording camera.

By cutting the Virtual Reality into two layers, it is possible to immerse into the Virtual Reality and getting obscured by virtual objects (as seen on Figure 4). The variable positions of the cutting plane, which is dividing the Virtual Reality into a foreground and a background scene, is calculated from the live position of the tracked Head Mounted Display (HMD).

OBS combines the video signals of the two virtual cameras and the third signal from the life camera and is able to stream the result to the internet. A chroma key filter on the live video record allows to suppress the green background and replace it with the virtual camera videos.

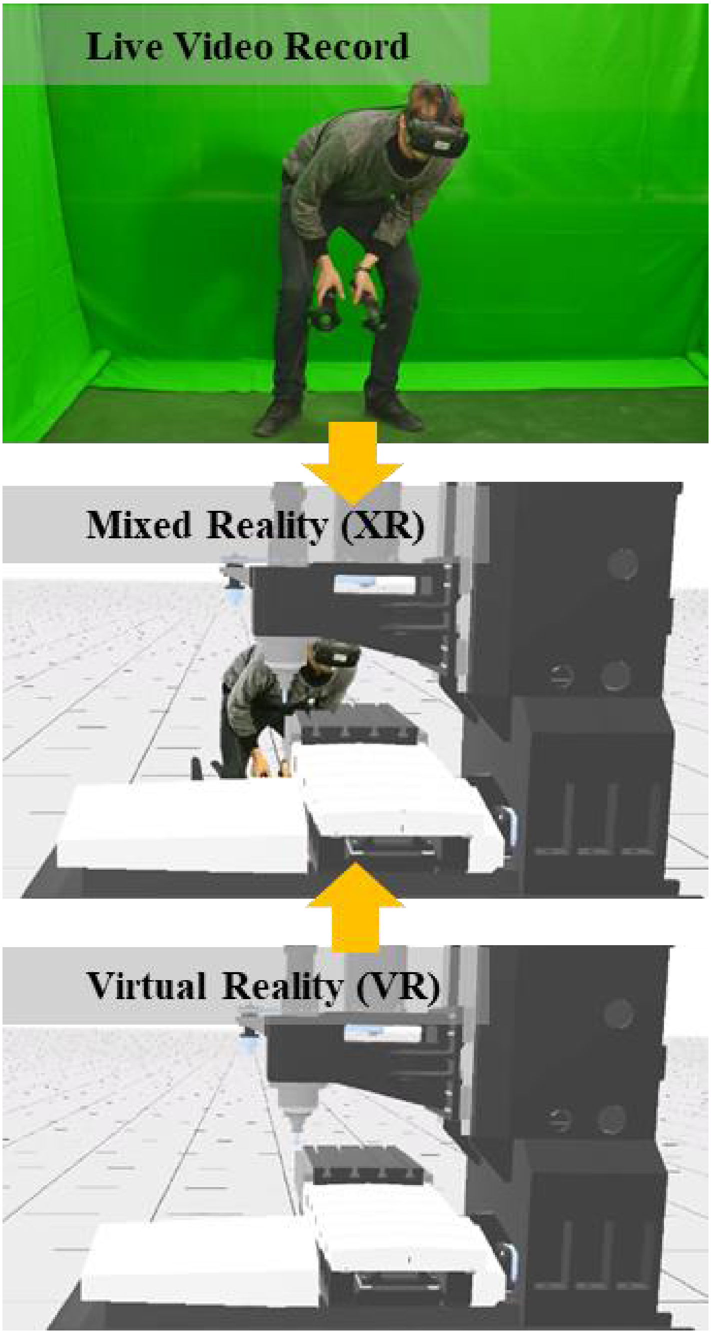

Figure 4. Set Up for Mixed Reality with GreenBox.

The recorded instructional videos can either be streamed as a live session directly to the machine operator or can also be stored in a database as ´how-to-guides´ to help with common problems in the future. All required hardware and software for this kind of application are included in the new developed mobile collaboration rack, so it is very easy to set up a session for remote maintenance, even for users, that are not extremely familiar with it.

6. Conclusion

There are hundreds of software solutions for all sorts of digital collaboration. It is very difficult to define and categorize all of them exactly, since most of them provide more than one of the needed functions at the same time e.g. chatting, video conferencing, file sharing and screen sharing.

The developed mobile environment has to prove itself in the daily work of the different use cases. In combination with the open source Riot Client, the decentralized Matrix Network offers an open standard with plenty of possibilities for interdisciplinary collaboration in research projects and other fields.

The use of Augmented and Virtual Reality technologies has enormous potential in the field of interdisciplinary collaboration between teams around the world. This was evaluated in the research project ´EMOKO´ at the University of Albstadt-Sigmaringen. It is easier to discuss technical matters with people that have a different professional background or different native language with the help of graphical simulation, because than it can be explained in Virtual Reality or Augmented Reality Model as graphical IT tools.

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Towards Energetic Autonomy of UAV

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Abstract. This article presents the results of work of power supply system of an unmanned aerial vehicle (UAV) powered by solar cells. The UAV power supply system consists of solar cells, a charge controller, battery cells and a BMS (Battery Management System). During the designing process various options for energy acquisition and recovery was considered, in particular ATG (Advanced Thermoelectric Generator). The MBD (Model-Based Design) methodology was used to develop the UAV power supply system. The system was developed in simulation model and next it was studied to find the space of possible solutions using this model. Solar cells are the most efficient if the sun rays fall on them perpendicular. During the simulation various angles of inclination of solar cells in relation to sun rays were studied. These values depend on latitude, azimuth, season (length of day), weatheri.e. if there are any clouds and even air pollution. The power supply system had to be constructed in such a way to ensure during the day excess to energy enabling the operation of the engines, peripheral devices (sensors, measuring devices, GPS module) as well as charging the batteries to maximum capacity. The next step was related to the proper selection of battery cells to ensure the operation of the devices and flight at night. The whole research was additionally extended by minimizing the mass of power supply elements while increasing the ability to achieve energy autonomy. The developed system allows to increase the UAV flight duration, and with appropriate construction, geographical location and favorable weather conditions it is able to provide full energy autonomy of the UAV. The UAV powered by solar cells enables for example monitoring of pollution, boundaries, power lines, crops and measuring selected physical quantities over any area e.g. smog.

Keywords. UAV, Model-Based Design, Solar-powered aircraft, Energy harvesting, Energy autonomy

Introduction

Electric vehicles are gaining more and more popularity. Into this group we can also include unmanned aerial vehicles (UAV). These innovative vehicles are increasingly used in everyday life. UAVs are used, among others for distributing shipments [1], but also for more advanced operations, e.g. monitoring of borders or crops [2,3]. Currently, the biggest problem associated with UAVs is the increase of flight duration for longer operations without unnecessary landing. For this purpose, a system should be developed that will not only increase the flight duration, but also optimize the system in terms of weight. Therefore, an innovative approach to solving the problem is necessary. One should strive to obtain energy from the outside, but also strive to reduce energy consumption. By using the Model-Based Design (MBD) method [4], it will be possible

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to analyze the power supply system in terms of energy demand, reduce the system weight to a minimum, and provide an energy surplus that will allow continuing operations at night [2,5]. The simulation should take into account various fields of technology that significantly affect the energy obtained by solar cells and energy demand. The results are influenced by, among others, flight mechanics (lift forces, drag) and aerodynamics for given conditions [6,7] i.e. flight altitude or speed. In addition to mechanics, electrotechnical issues related to the design of energy-saving systems, processing and storage of energy should also be taken into account. Each simulation model can be further optimized for other solutions. It can be scalable and detailed by changing technical parameters for any individual subsystems.

1. Energy autonomy

The main problem that currently occurs in the case of electric UAVs is the limited battery capacity which causes limited flight duration. There is a possibility of adding more battery cells but it will increase the weight of the vehicle. This is especially important for flying vehicles, where weight plays a very important role. The goal is to build the lightest aircraft possible. Energy storage sources are becoming more and more innovative, however, energy density remains the most important challenege for batteries. To increase flight duration and even ensure full energy autonomy, UAV aims to obtain energy from outside. One of the possibilities is obtaining solar energy through solar cells mounted on the aircraft structure. Another alternative is the use of the Advanced Thermoelectric Generator (ATG). ATG works on the principle of the Peltier phenomenon. The temperature difference between the two surfaces makes it possible to generate the electrical voltage needed to charge batteries or power electric drives. It is possible to use a hybrid system. One of the methods is to combine a solar power supply system with ATG [8].

To increase the efficiency of energy conversion, it is also possible to use supercapacitors. Their biggest advantage is short charging time, but also high efficiency and lifetime as well as high value of unit power (W/kg - about 10 times higher than for lead-acid batteries). Due to the low internal resistance, it is possible to draw and release large currents in a short time. The disadvantage of supercapacitors is the low voltage of one element, however, the assembly of individual parts into serial, parallel or mixed modules is very simple. Supercapacitors can be connected together in the same way as individual battery cells [9].

The use of hydrogen fuel is another alternative to the UAV power supply system. The use of hydrogen as a fuel works well in vehicles where mass plays a greater role than volume, e.g. rockets, aircrafts. The downside ofthis solution is the inability to achieve full energy autonomy of the vehicle in a technically easy way. A hydrogen fueled vehicle is also certainly the most complicated to build, and the integration of individual modules requires the involvement of specialists from many industries in the project [10]. The alternative is also to combine the above methods with a certain percentage in one hybrid power system. The biggest disadvantage of this solution is the very high complexity of power supply system. Along with a more complex system, mass is also increasing. The complexity of the system can cause many problems related to UAV repair and maintenance [11].

UAV's power supply system can be build using many different power sources and storage sources (Fig.1). In the Fig.1 power sources and storage sources are gathered in one group as elements thanks to which electrical consumption devices are able to work. In our case study we want to develop power supply system for HALE (High-Altitude Long Endurance) which ultimately is to fly in the stratosphere. In HALE we can not use all power and storage sources. Some part of them will be not effective e.g. ATG. In the UAV temperature differences is most of the order of a few tens of degrees centigrade. This cause that this power source will not be efficient enough. Also supercapacitors will not be good choice as storage source for HALE. Supercapacitors can be use as storage source for FC(Fuel Cell) and only in the case of high dynamics of energy demand change but not for PV(Photovoltaics) powered facility with an even and slowly varying energy demand. For HALE the best options seems to be solar cells. In this article are the results of work on the power supply system for UAV which is powered by solar cells.

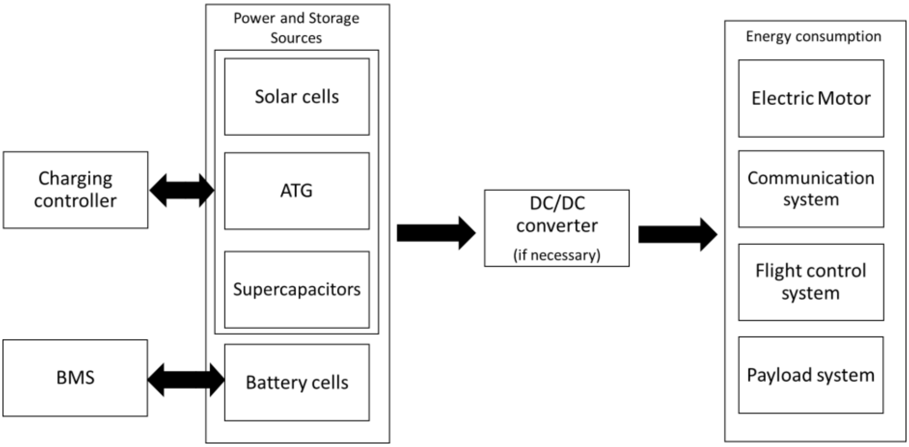

Figure 1. General scheme of UAV's power supply subsystems.

2. Methods of analysis of energy-efficient systems

The aim of energy efficiency analysis is to maximize flight duration and even ensure full energy autonomy. One of the methods to increase flight duration is to use solar cells. The solar cells power supply system consists of solar cells, charging regulator and battery cells. The only unknown value is the value of energy that can be obtained at a given time t[s] from solar cells. The value of the power obtained by solar cells depends on several factors, among others:

- flight altitude
- angle of the sun towering over the horizon
- azimuth angle,
- seasons (duration of the day),
- cloud cover, fog
- air pollution

In the initial phase, it essential is to read the information that limits the access of sunlight, i.e. the angle of the sun towering over the horizon and the azimuth angle. Theinformation is directly related to the seasons, due to which the duration of day and night is constantly changing (the exception is the equator). Depending on the latitude the first angle of incidence of sunlight differs. This value is associated with the earth's circulation and is different every day. The second value is the azimuth angle, which changes all the time during the day. It depends on the rotation of the earth. The graph below shows how the solar cells performance changes for given angles of the sun towering over the horizon and azimuth angles(Fig. 2). The value is the resultant of sine angles of sun towering over the horizon and azimuth. We can use below equation to describe it as:

$$performance = sin\alpha \times sin\beta \tag{1}$$

Where:
$sin\alpha$ – sine angle of the sun towering over the horizon
$sin\beta$ – sine angle of the azimuth

Cloudiness and air pollution are values that are studied by meteorological institutes. This data varies depending on location, season and weather conditions. The octane scale is used to determine cloud cover (from 0 - no cloud cover, to 8 - full cloud cover). In addition to the degree of sky coverage by clouds, the type and typess of clouds are also given. All this information has an impact on the value that we will finally get as input power to the power supply system [12,13]. The percentage values for the perpendicular angle of sunlight in the octane scale from 0 to 8 can be defined as: for 0 - 100%, 1 - 98%, 2 - 94%, 3 - 88%, 4 - 79%, 5 - 70%, 6 - 54%, 7 - 50%, 8 - 27% [11].

The last variable that affects the value of the obtained power is air pollution. This value not only contains data concern on smog, but also dust layers that settle on solar cells. It is very important to determine the location of operations performed by UAVs. In the winter, soot accumulates on the solar cells, in addition we have to deal with dust. Also, moisture in the air can limit the value of obtained power. There may be frost or rime on the solar cells. Desert dust may occur in desert areas, which will also reduce the value of supplied power [14].

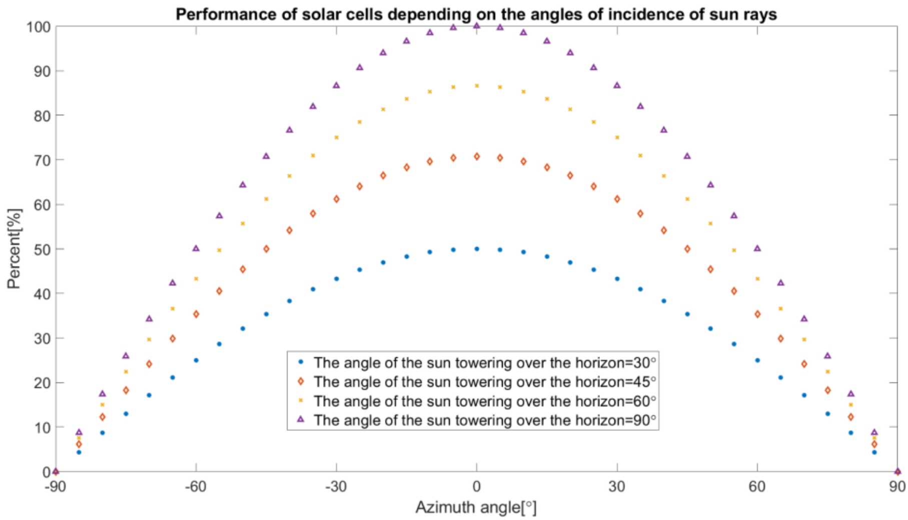

Figure 2. Graph of solar cells performance depending on the angle of incidence of sun rays.

3. Case study – energy-efficient UAV

3.1. Assumptions for energy-efficient UAV

The object that was analyzed is UAV, which is to fly in the stratosphere (TWIN STRATOS). Its main source of power are solar cells (Fig. 3). Based on the construction data and flight parameters, the elements of the power supply system and the propulsion system were selected. The most important parameters of TWIN STRATOS:

- Mass: 70[kg]
- Wingspan: 24 800 [mm]
- Area of the wings: 34.6 $[m^2]$
- Area of tail-plane: 7 $[m^2]$
- Area of the solar cells: 19.7 $[m^2]$

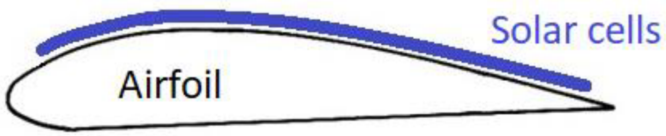

Figure 3. Solar cells attachment point on the Twin Stratos wing.

Solar cells and batteries are important elements of the system. Their selection is to ensure UAV full energy autonomy, with the lowest possible weight of the system. The power system is based on a voltage of 48 [V]. Initial parameters of the power supply system were determined on the basis of simplified analytical calculations. Thanks to them, the number of solar cells and batteries has been preselected. Another approximation is the analysis presented in the article. The battery capacity was initially determined as 72.5 [Ah] to provide the flight for 12h at height 5500m at night. A UAV flight simulation scenario was also developed (Fig. 4), which took into account the basic operations performed during the flight. The scenario helps in the of UAV energy demand so that it is possible to determine the power needed for take-off, altitude maintenance, climbing and landing.

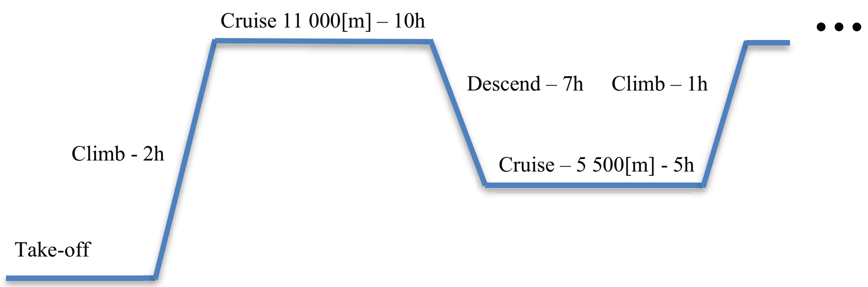

Figure 4. UAV flight scenario included in the simulation.

The last issue is the selection of batteries to accumulate energy and ensure the operation of the system for the longest possible time. The technical parameters of the whole system should be consistent. The propulsion system, flight control system, communication and payload can be supplied with different voltages. For this reason, DC/DC converters must be used. The elements of the power supply system should take into account the lowest possible mass of the system and ensure safety and prevent short circuits and explosions of the battery cells.

3.2. Concept of solar power supply system

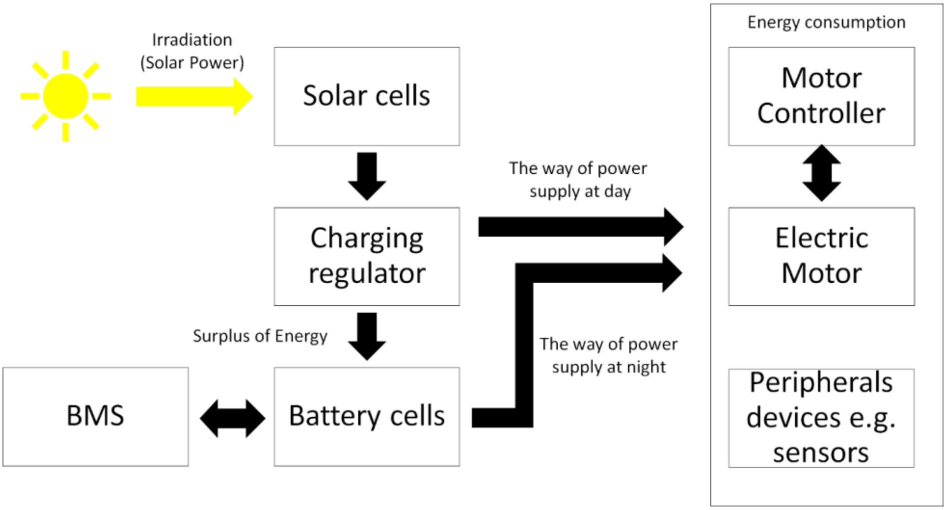

Figure 5. Schematic diagram of the power supply system.

The study assumed that the length of the day would be limited to 12 hours (to the equinoxes). Thanks to this initial thesis, it will be later possible to decide whether the received power is sufficient and the research can be directed to increase the length of the night or on the contrary, the day duration for operation should be extended. The area of Poland was adopted as the location for the study. Data regarding the angle of the sun over the horizon and azimuth angles were obtained from calculators [15]. Cloudiness values and value of air pollution, were omitted in the preliminary tests. We assumed to start UAV in sunny day. For our assumptions, i.e. the location adopted for Poland and the spring or autumn equinox, air pollution will not be as important as e.g. in the winter, when we deal with the biggest pollution e.g. smoke form chimneys. In this case air pollution has been omitted.

The power supply diagram (Fig. 5) helped developed a model for analysis. This is a special case of the HALE power supply system based on Fig.1. It is based on solar cells as power source and battery cells as storage source. The system simulation model was developed based on a single solar cell subsystem (Fig. 6). The cells are connected in series and in parallel, respectively, to ensure proper voltage and output current. The input value is the product of the sun irradiation (~1000W/m^2), the angle of incidence of sunlight relative to solar cells, cloud cover [%] and air pollution [%]. The analyzed

HALE is beyond the influence of weather phenomena having a significant impact on solar radiation. In this case and approximation cloud cover has been omitted. Significant impact on this type of phenomena occurs in the case of LALE(Low-Altitude Long-Endurance).

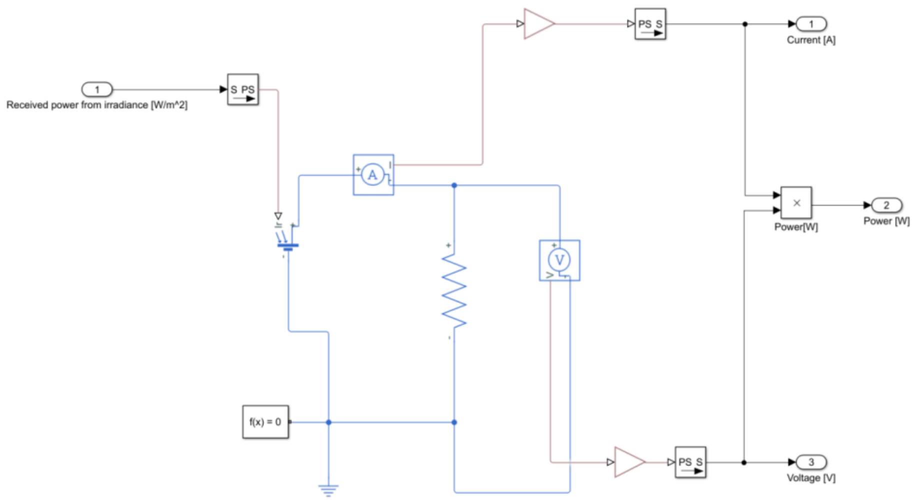

Figure 6. Single solar cell model.

In addition to the solar cell model, a battery discharge and charging model was also developed (Fig. 7). This model is to determine the energy balance and check properly connected batteries in modules which are able to provide flight maintenance for UAV at night (t=12h).

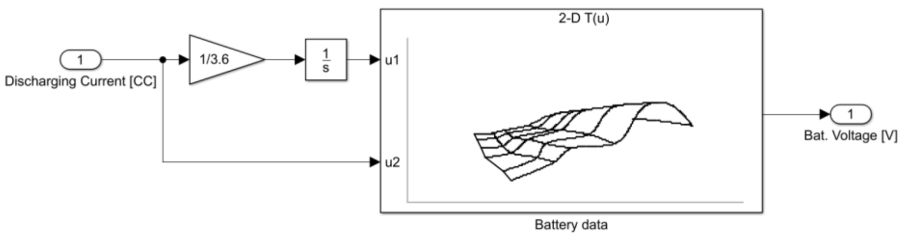

Figure 7. Model of charging and discharging the battery.

The Battery data block contains the values of discharge currents, capacitance and voltage of Li-Ion cells. Thanks to this data, it is possible to perform a simulation that illustrates how the battery will behave after loading with the set current value I [A].

The single models were combined into subsystems and then integrated into one system, enabling the simulation of energy balance for UAV powered by solar cells.

3.3. Analysis of energy consumption in various operational states

Energy demand data for various TWIN STRATOS flight scenarios was developed by aviation constructors and designers. The extract from this data let calculate the energy consumption for the main flight phases (Table 1). In simulation model we used this values as constant to check the duration of flight and discharging time of the batteries.

Table 1. Energy consumption for main phases of flight for the UAV model.

Flight phase	Energy demand
Take-off and climb V = 90km/h	1100[W]
Cruise speed V= 55km/h h=11km	500[W]
Average power needed to maintain flight at night V=24km/h, h=5.5km	250[W]

Initial analysis of the maximum energy consumption is about 1200W, including the operation of additional devices (camera, GPS module, servos). The solar cells are able to provide a maximum of about 2500W. With this information, we are able to determine what voltage and current are able to "flow" to recharge the batteries. The data obtained in the simulation allow to state that the energy surplus during the day will easily charge the batteries to their maximum capacity during 12 hours of sunlight (Fig. 8). The guideline was also to take into account the margin of energy surplus for decisions in the event of a breakdown or other technical faults. This time has been initially set to 4 hours. The below chart shows linear approximation of the power consumption and power demand. We assumed that the UAV would take off with a discharged battery to check if the surplus energy from solar cells would be able to charge the batteries during the day. To prepare more detailed chart we have to use equation related to movement of the sun for a given localization, taking into account also movement of the UAV.

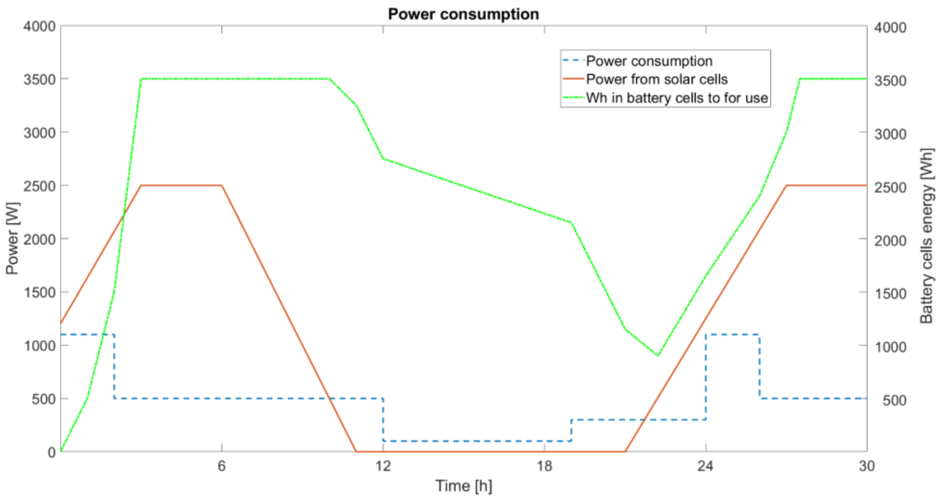

Figure 8. Energy demand graph for the example of TWIN STRATOS mission (from Fig.2).

Battery discharge analysis was based on three scenarios:

- Scenario 1 – maintaining flight at night at an altitude of 11,000 [m]
- Scenario 2 – gliding from 11,000 [m] to 1,000 [m], next climbing to 11,000 [m]
- Scenario 3 - gliding from 11,000 [m] to 5,500 [m] and then maintaining the flight at this altitude (Fig. 4)

The analysis of battery discharges at night shows that the power needed to maintain the flight at night discharges the batteries after a maximum of about 19.5 hours. This analysis included gliding of UAV for 7 hours (scenario 3). The result is minimal power consumption and a minimum sink rate(~ 0.2m/s). Gliding allows to use potential energy, so that for some time electric motors do not need to draw electricity from batteries (Fig. 9).

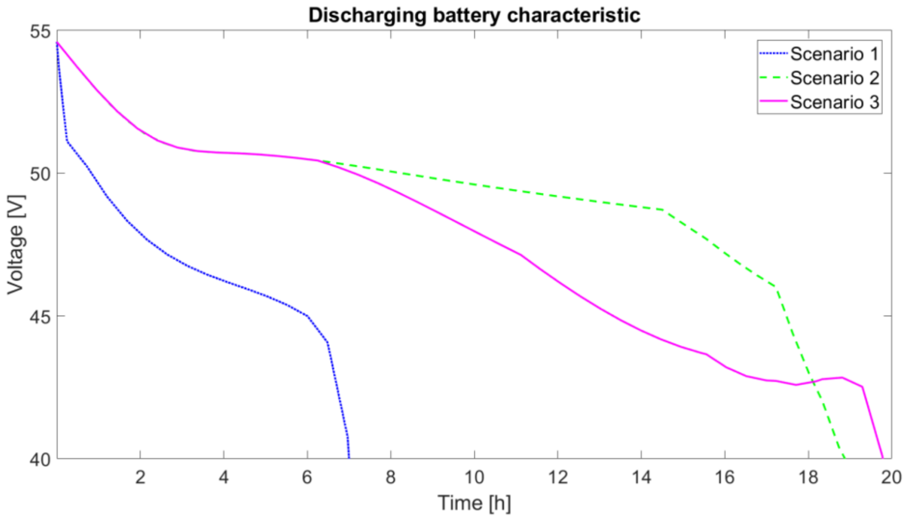

Figure 9. Battery discharge characteristics for different scenarios.

The comparision of scenarios 2 and 3 shows that the batery discharge time is similar. The most energy consuming is scenario 1. This analysis shows that except for the the energy stored in batteries it is also worth to use potential energy as time buffer. This will help to increase the duration of the flight.

4. Discussion of results and conclusions

Designing a solar powered UAV system is not only the field of electrical engineering, but also aviation mechanics, meteorology, astronomy and environmental protection. We should strive to develop a system that will satisfy and be able to ensure full UAV energy autonomy. Analysis of Fig.8 shows that the number of solar cells used in the simulation is sufficient. For prepared scenarios surplus of energy is significant and is not used in full. We can decide on two ways of action. First is connected with limiting the number of solar cells. Second is to increase the capacity of batteries. First way will allow to decrease the mass of the power supply system but also can cause shorter ranges in adverse weather conditions. Increasing the mass of batteries increase the range of UAV but mass is on of the most critical values so probably this way will be suitable only for relevant restrictions. Additionally we can reduce the batteries due to the use of potential energy. Developed simulations show that gliding can increase time of flight relative to maintaining the flight at least twice. It all depends on the starting ceiling. Before taking the road we have to prepare more detailed simulation model for specific flight scenarios and for specific latitude and flight conditions. Initial assessment is a somewhat hypothetical condition. A more detailed model will allow to specify critical locations, e.g. polar zones. Methods will be sought for modeling a hybrid UAV power system system and also for reducing the system's complexity.

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scone – A Requirements Management Tool for the Specification and Variability-Based Analysis of Product Lines

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Abstract. Nowadays, industrial products as well as software applications are expected to be tailored to the user's needs in an increasingly distinct manner. This often makes it necessary to design a vast number of customized variants, which leads to complex and error prone analysis and development processes. Generally, requirements engineering is considered to be one of the most significant activities in software and system development. Variant management has proven to play an important role in handling the complexity arising from mass-customization of products. However, there are only a few, often rather complex-to-use, applications which allow adding variance information directly to requirements. Especially in case of small and medium sized enterprises, approaches to meet this challenge often result in isolated solutions that are not driven by state-of-the-art analysis methods and do not cope with future requirements. This paper introduces a lightweight requirements management tool called scone, which will be embedded into an overall variability management methodology. scone enables the user to create and manage requirement specifications and augment them with variability information. Based on this specification, the requirements can be analyzed in a formal way with respect to their variability using the variability management tool Glencoe. scone was created as a single-page web application to eliminate the need for installation and allow it to run on many devices, while offering the experience of working with a native application, rather than a website. Both tools are designed to provide a proof of concept for the seamless integration of variability information within a system development process as well as to show how variability can be handled in an easy-to-use way from the very beginning within this process.

Keywords. Requirements engineering, product line engineering, variant management, collaborative teamwork, design of personalized products and services

Introduction

The quality of a product significantly depends on the extent to which it meets its requirements. Therefore, it is commonly accepted that requirements management plays a key role in the development process. Defects and errors that are noticed and fixed at the beginning of a development cost very little, whereas a mistake that is discovered after delivery can cause great damage. This situation becomes even worse when variability is considered, which greatly increases the complexity of the products developed. Growing customer demands and expectations make it necessary to create multi-variant products that are able to meet a broader spectrum of needs. In industrial projects the difficulties

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associated with the described situation are apparently often avoided by initially ignoring variability. Only the requirements are described and variants are added at a later and therefore often inappropriate stage in development. The automotive industry has learned from this situation and has established a professional platform-based variant development process that allows to cope with the described difficulties. Although well-established companies have partly mastered the problem, it remains a challenge for small and medium-sized companies to integrate requirements management and variant management successfully and cost-effectively into their overall development processes.

At Trier University of Applied Sciences an application called Glencoe[2] is being developed since 2012 with which multi-variant product lines can be specified, visualized and formally analyzed. It is a web application which provides the user with the possibility to create and edit feature models in an accessible and user-friendly way. Since requirements management and variability are closely connected we developed an easy-to-use tool for requirements management and extended it with functionality for adding variance information to the requirements specification.

In this paper we present an easy to use platform independent requirements engineering tool that besides the usual functionality allows to specify variance information on requirements level. A loose, partly automated, integration with Glencoe gives the user the possibility to build a variability perspective on its requirements specification. This perspective can be used by several stakeholders involved in the project to clarify open questions concerning variability across disciplines.

1. Initial considerations

1.1 Obstacles for small teams

As part of the planed overall development methodology [3] scone has to follow the development paradigm to keep things as simple as possible for the user. As part of the previous work [1], in which a first prototype of scone was designed and implemented, a survey on requirements management was conducted with the aim to find reasons why requirements engineering was not successfully applied during a product development. The participants' main reasons for not carrying out requirements management were:

- There was no time. Requirements management would have been too time consuming.
- The Participants stated that there was no need for requirements management because the project was so small.

Furthermore, the participants argued that in case they did apply requirements management they decided against using a professional tool because:

- The effort to become familiar with the tool was too high.
- There had to be too much research to do.
- The tools are too complex.

[2] https://www.glencoe.hochschule-trier.de

We could not find any studies on the influence of the existing range of applications on the actual implementation of requirements management. Thus, the following considerations are only based on the survey conducted.

The reasons for the rejection of a professional tool may be due to the fact that standard industrial applications are suitable for a great variety of projects and therefor possess a vast number of – for small projects often – unneeded features that can initially be overwhelming to the user. If these tools are not documented well enough, or conversely have a relatively extensive documentation resulting from the number of features and use cases, users may find it difficult and too time consuming to learn how to use the tool and to familiarize themselves with it. According to [2] helpful resources like user guides and example solutions are often not available, making it harder for the user to learn how to use a tool. Novice users in particular may be put off and prefer using non-professional or not well-suited tools that are easy to use and well understood, or even stop performing requirements management altogether.

Another reason for small teams to reject professional tools may stem from the time needed to set up the tool or rather that there is no easy access. According to a systematic literature review [2] which compared 41 requirements management tools, the vast majority of the tools are not online, meaning the user needs to set up a tool on premise. More than half of the tools come as plugins, that require other already established and understood software and cannot be used alone, which means an additional obstacle for small teams and inexperienced users [2].

1.2 Mapping a requirements specification to a feature model

Requirements management is often the first step in system development, which nowadays often involves several disciplines. Together, they try to work out a specification that reflects the requirements of different users in different variations. In order to overcome the before mentioned shortcomings we started to implement the tools to realize our before mentioned overall methodology. Since requirements management and variability are closely connected and Glencoe was already in place, we wanted to leverage the advantages of both tools to provide the user with the possibility to specify requirements for product lines and to visualize and analyze variability related properties in Glencoe. The variability information of the requirements specification has to be converted (automatically) into a corresponding feature model, that is delivered to Glencoe. This way the variability perspective on the specified product could be automatically generated and all the variant dependent information could be visualized to the user in a so-called Glencoe Feature Model (GFM) (see [3] for more on GFMs). Using this perspective gives the user also the possibility to analyze the specified variability using the built-in formal analysis operations, as there is a consistency checker, a dead feature checker or to count the number of different product variants to name just a few.

One challenge was to make sure that the considerations described in 1.1 are not neglected and that the features for specifying requirements and variability in scone do not collide with the ease-of-use paradigm. Emphasis was placed on enabling the user to specify requirements without having to know product line management and without the need to understand and learn the corresponding features of scone, so that the user will not be discouraged.

2. scone

Considering the results of the aforementioned survey and our own experiences in using tools for requirements management while simultaneously learning how to perform requirements management and variant management, we wanted to create a tool that allows even small teams to carry out requirements management without having to invest much time in mastering the tool. Since we wanted to develop an application that is intuitive to use and can be utilized without much extra effort, we reduced the functionality to the most basic functions needed to perform requirements management. This scope of the functionality is described in detail in [1].

The first prototype of scone was developed in 2017 with the intention of making requirements management accessible to students in university sized projects. In 2018 the application was redesigned and extended with a connection to Glencoe in order to deal with variability management. Nevertheless, its use should remain as straightforward as possible. scone currently enables the user to create requirement specifications and offers the possibility to augment requirements with additional variability information. The requirements can then be visualized and analyzed with the help of Glencoe and the results of the analysis can be leveraged by the user to adjust the requirements specification and the corresponding variability information in scone.

2.1 Extension of the requirements specification

The first prototype of scone represented requirements as a simple list (see Figure 1, left side) with no possibility of defining a hierarchy. Sub-systems and different parts of products are often hierarchical in nature and feature models contain features in hierarchies. The first step in mapping a requirements specification to a feature model is to gather corresponding requirements for clearly distinguishable features and to provide a possibility to create hierarchies. For the sake of this we introduced Requirement Groups (RGs). Every project created in scone initially contains a root requirement group. Subsequently requirements and other RGs can be defined in it. Thus, the hierarchical nature of a product can be represented, as every feature is described by one RG containing all requirements for that feature and other RGs for its sub-features (see Figure 1, right side). The grouping of the RGs serves to improve exportability as a Glencoe feature model as well as to structure the requirements specification, since they also function as headings. Furthermore, they can be used to describe variants of product features, where one requirement group would gather all requirements and RGs for a variant.

To emulate the logical relationships between features, scone uses the same types as Glencoe. It is possible to define RGs as *Feature* (the content of the RG describes one distinct product feature), *Alternative* (the content of the RG consists of alternatives of which only one can be part of a valid product), or *Selection* (only a certain number of the direct children of the RG can be part of a valid product).

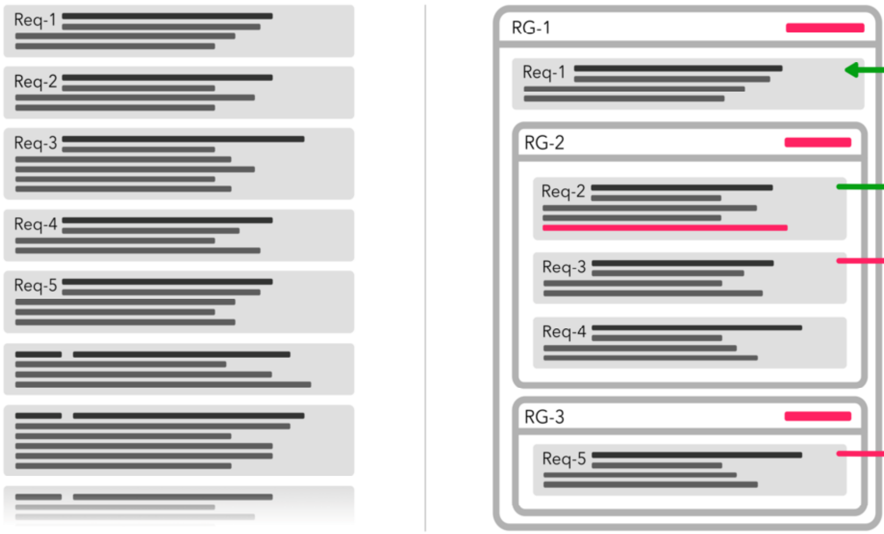

Figure 1. Schematic view of the representation of the requirements at the starting point and in the as-is situation in scone. The left side shows a list of requirements without hierarchical order and variance information. The right part of the figure shows the requirements aggregated in requirement groups with colored variance (excludes and implies) information.

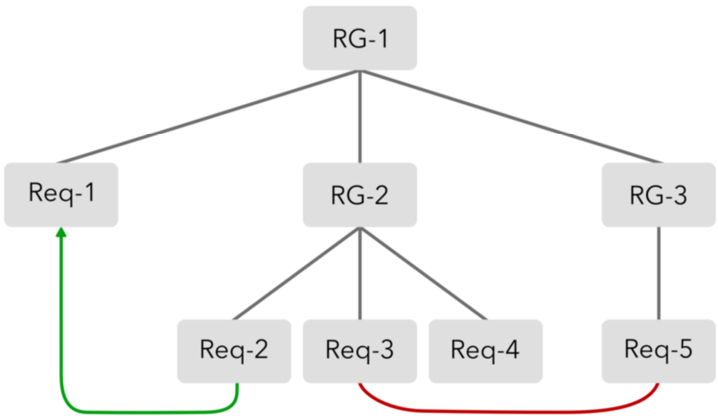

Figure 2. The example requirement specification from figure 1 displayed as a feature model.

2.2 Handling of constraints

To express inter-dependencies between features and variants, we added the possibility to define constraints for requirements and RGs which are called *links* in scone. There are mainly three types of links: *excludes* (if A is part of the product, B cannot be and vice versa), *requires* (if A is part of the product, B must be, too), and *refines* (A further defines B), with refines being a constraint that can only be used for requirements. The first two translate directly to their Glencoe equivalents *Requirement* and *Mutual Exclusion*. The refines-constraint translates to two linked features, A and B, with B being the child of A. A schematic view of requirements with constraints can be seen in figure 1 on the right side.

2.3 Working with scone and Glencoe

The transmission of variant information from scone to Glencoe can be performed by the user at the desired stage of development. Thus, a variability view (see figure 2 for an example) is generated which can be visualized and analyzed in Glencoe. If errors or defects are detected, the corresponding experts have to be contacted in order to fix these problems at a very early stage during the development. Besides the possibility to formally analyze the variability of the product line the requirements engineer and the variability engineer can work together on the basis of the visualized feature model to define the appropriate variability.

As both tools put their emphasis on being easy to use and the visualization provided by Glencoe serves a better understanding of the product, also non-technical users can be more closely involved in the process. Furthermore, the visualization of the requirements specification can be used to create a shared understanding of the product and to facilitate cooperation in a project as mentioned before.

Figure 3 shows a screenshot of scone illustrating requirement groups, subgroups and requirements. An export of this requirement specification results in a Glencoe feature model that can be directly imported and visualized in Glencoe, for example using the Tree view – a representation based on the FODA notation, which was introduced in 1990 by Kang et al. [4] –, as shown in Figure 4.

If errors, like inconsistencies or dead features, are found, the requirements specification can be corrected in scone as needed. The cooperation of both tools makes it possible to detect errors or flaws in a very early stage of development, which can help to drastically shorten the development time and effectively reduce costs. Furthermore, it improves the understanding of the product and its variability as the analysis procedures of Glencoe help give some more insight into the specified variability as there are metrics to find common features, unique features and compute all possible configurations.

Figure 4 shows the analyzed sample project where Glencoe has found two dead features (crossed out red), meaning these features are not part of any configuration. Those could either result from errors in the specification that can subsequently be corrected, or the corresponding requirements are simply not needed and may be omitted. At this stage a decision has to be made how to handle such an error. Glencoe supports the user by providing an interactive proof representation that allows the user to identify possible causes for this defect. See [3] for more information on the formal analysis procedures used in Glencoe.

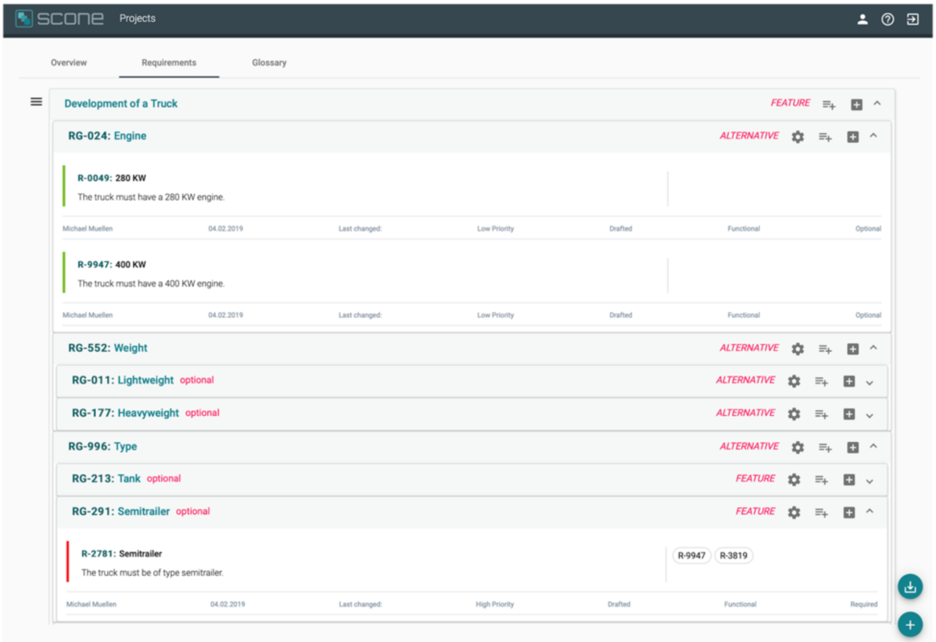

Figure 3. View of the requirements specification with variance information within scone.

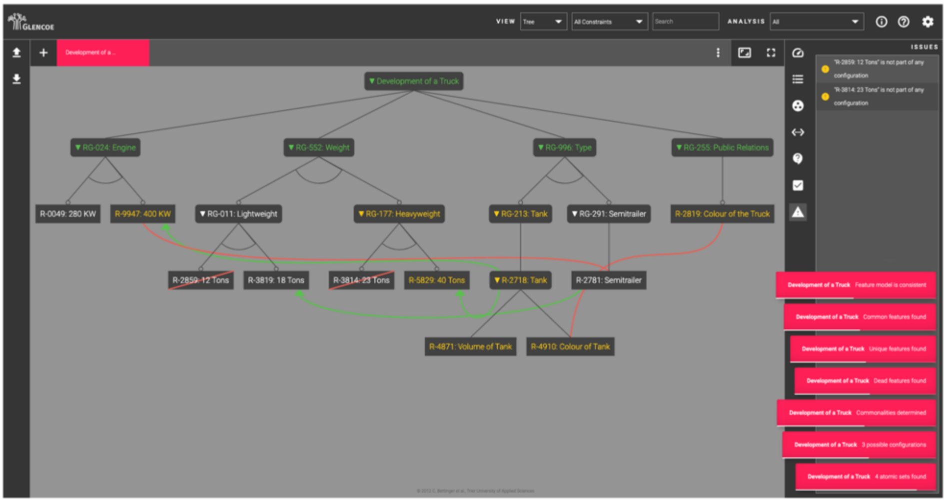

Figure 4. The requirements from figure 3, exported from scone and visualized with Glencoe. The feature model has been analyzed.

3. Technical realization

In order to ensure that collaboration on the requirements specification is as simple as possible, scone was implemented as a single-page web application. This section gives a brief overview of the architecture of the application.

In broad terms, the application can be divided into frontend and backend. Both of these parts are located on the server, but the code for the frontend is used for visualization and logic of the application in the user's browser, while the code for the backend handles the processing of data.

As shown in Figure 5, the backend uses a database, in which all persistent data required by the application is stored. The frontend is formed by a single-page application created with Angular, extended with an NgRx store for state management. The latter helps to improve the performance of the application while ensuring data consistency. The Angular application communicates with Django via the REST interface, which processes HTTP requests, or via Django Channels which, in concert with Redis, handles web socket connections used for real-time functionalities in scone.

The implemented real-time functionalities serve the purpose of keeping the requirements specification up to date for all members of a team, as changes are automatically propagated to them with an accompanying notification. This is especially helpful for remotely working teams.

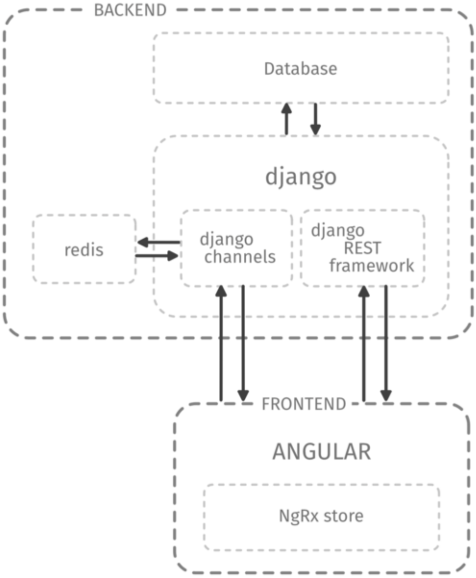

Figure 5. Server architecture of scone.

4. Validation of the implemented tool

At present, the tool is used in the context of lectures by students. This is the first step to evaluate the functionality according to the following questions:

- Is the functional scope of the application sufficient?
- How do users rate the usability?
- How long does it take users to become familiar with the application?
- Are the benefits of the application so great that users would prefer it to a text document or spreadsheet for small projects?
- Could the benefits of the application convince users who do not want to do requirements management because their project is so small?

As described above, scone provides only the most basic features needed to perform requirements management. It is now to be determined if the features at hand are sufficient to efficiently carry out requirements management and how they can be improved in any way.

Since the main goal was to develop an application that is easy to use, usability has to be determined in an acceptance test. As part of a university seminar, small groups of users who mostly have never applied a requirement engineering tool will use scone during a several weeks lasting project. After this period the users will evaluate the user experience and point out potential problems.

5. Related work

There are several product line applications available, including pure::variants [7], SPLOT [8] [9], and FaMa[10]. However, the study of Pereira et al. [2] shows that 51% of the reviewed applications are plugins for other applications and only 17% are online. Of those 17% only two, the DOORS extension [11] and Metadoc FM [12] provide support for the inclusion of requirements. Both tools are plugins for IBM Rational DOORS, with the DOORS extension being just a prototype. Neither of them is free to use [2].

6. Conclusion and future work

During the development of scone, the emphasis was placed on user-friendliness and simplicity of use. A basis was created to supplement the requirements specifications with variance information which can be analyzed and visualized with the help of Glencoe.

The result is an easy-to-use web application that allows both novice and professional users, regardless of the platform used, to create requirement specifications even in distributed teams. Due to the possibility to enrich the requirements with variance information and the integration with Glencoe for analysis, requirements management and product line management can be applied in conjunction. This can lead to an early error detection and a better understanding of the product to be created resulting in a more efficient and effective development process.

We argue in the paper that different disciplines must work together in the context of requirements and variant management. To our experience and to our best knowledge it is often the case, that variant management is (if at all) considered at the very end of a project. The reasons are in most cases obvious, but result often in a pure variability concept. The integration of the tools described in this paper gives the possibility to overcome this defect at a very early stage of development and with very little effort on the tool side.

We expect greater acceptance and a lower hurdle in the introduction of an integrated variant management methodology, especially among small and medium-sized companies.

However, the integration of scone and Glencoe has to be improved, since it is currently still necessary to first export the requirements specification from scone and then import it into Glencoe. We are currently working on a closer integration of both tools allowing for a seamless roundtrip from scone to Glencoe and back again without the need for manual intervention. Thus, it would be possible to fix inconsistencies directly in Glencoe with the changes automatically being reflected to the requirements specification in scone. This would realize a completely seamless workflow during the development process, leading to an easy to use analysis and error correction mode of operation.

Furthermore, it is currently not possible to import requirement specifications to scone. It is planned to realize the import of ReqIF [4] conform specifications in order to support interoperability with well-established requirements engineering applications. However, the possibility to import other common formats like CSV should be added too.

In order to further consolidate the user-friendly approach, more research is needed in this area, particularly with regard to requirements management, as most studies focus on methodology and techniques rather than on usability and user-interaction.

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Multi-Disciplinary Optimisation Framework for Dual-Mode Launch Vehicle Concepts

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Abstract. Increasing demand for small satellite launch capability provides scope for the development of cost-efficient innovative payload delivery services. The advantages of air-launch capability are well-documented through the success of the Pegasus launch vehicle, but vertical ground-based takeoff is still the standard approach. This project details a transdisciplinary approach to designing a novel dual-mode launch vehicle with air and ground launch capability, for small satellites. The vehicle's mission is determined to achieve a payload capacity of 50kg to a 700km sun-synchronous orbit. Alongside the vehicle design, potential carrier aircraft are assessed, and the interface between the two evaluated for feasibility. The proposed air-launch vehicle is a 3-stage HTPB solid rocket weighing just over 2.5t, with two 775kg strap-on boosters for ground-launch. Both the air-launch and ground-launch solutions are verified with the launch optimiser program ASTOS. Future subsystem studies are proposed for further refinement.

Keywords. Nano Satellites, Launch Vehicles, Multi-Disciplinary Design, Modular Design

Introduction

The number of nanosatellites (1kg - 10kg) and microsatellites (10kg - 100kg) launched per year is growing due to increased commercial demand (Figure 1). Current studies predict the continuation of this trend well into the future [3]. The design of a new launch system requires many disperate requirements to be met and hence a transdisciplinary approach is required to obtain a balanced solution. These requirements are technical, economics and safety. Economical aspects are addressed by proposing a modular launch vehicle that can be ground launched or air launched as per customer requirements. This dual-mode solution offers flexibility and increases launch capability. Future concepts for cost reduction could be reusability of the first stage, e.g. by powered return or winged fly back. Safety is related to potential launch failure, inflight breakup and risk associated with falling debris. The technical challenges are in optimisation of the vehicle configuration to suit dual-mode options with a high level of commonality.

The majority of these satellites are used for Earth observation operating in Low Earth Orbit (LEO) [3]. Australia is well placed to benefit from participation in this growing sector of small satellite launch activity but is currently lacking infrastructure required for frequent launches to match the growing global demand.

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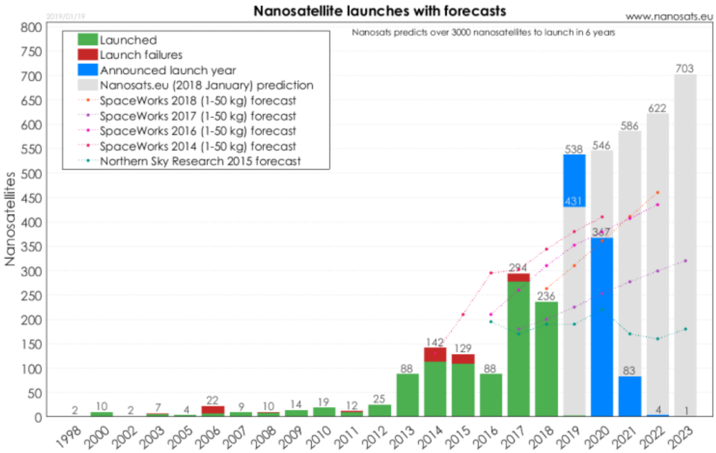

Figure 1: Predicted growth of nanosatellite launches [3].

Frequent and flexible launches of satellites up to 50kg to LEO should be a preliminary goal for Australian space operations if the intent is to capitalise on the growing commercial space industry. Currently, Australia does not have a commercially accessible orbital launch pad. The development of the new Whalers Way Orbital Launch Complex is proposed and will undoubtedly be in high demand (Figure 2). An air-launch capable vehicle bypasses this, at least in a technical sense, by enabling takeoff from a standard runway; the orbital vehicle can then be launched from altitude at a remote location. It is anticipated that this flexibility will be essential for time-critical missions while the demand at Whalers Way is high. Other Australian launch sites are also being considered, particular near the north coast.

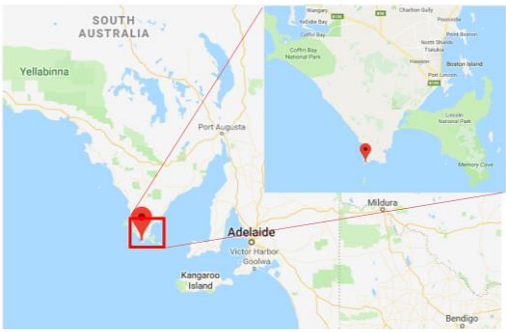

Figure 2: Whalers Way launch site location.

Ground launches, however, are well understood and easily regulated. As air-launch operations add legislative complexity that may be a deterrent for some time, development of a ground-launch capability may be the priority. To address both of these needs a Dual-Mode Launch Vehicle (DMLV), capable of launching from either a carrier aircraft or from a launchpad with minimal modification is proposed. The design of a new launch system requires many disparate requirements to be met and hence a transdisciplinary approach is needed to obtain a balanced solution. These requirements are technical, economics and safety. Economic aspects are addressed by proposing a modular launch vehicle that can be ground-launched or air-launched as per customer requirements. This dual-mode solution offers flexibility and increases launch capability. Future concepts for cost reduction could be reusability of the first stage, e.g. by powered return or winged fly back. Safety is related to potential launch failure, inflight breakup and risk associated with falling debris, which affects the choice of potential launch sites and flight paths. The technical challenges are in optimisation of the vehicle configuration to suit dual-mode options with a high level of commonality.

1. Methodology

The design of a launch vehicle encompasses a range of engineering disciplines, each discipline contributing to multiple parts and functionalities. At the conceptual design stage, these must all be considered simultaneously, as the properties of each part or system can have significant effects on another. French (2010) provides a summary of functional considerations in designing a generic launch vehicle, which helped guide the scope definition of the DMLV [1]. The other primary resource drawn upon in this process is the report published by Orbital (1993) detailing their transition from the Pegasus/B52 system to the Pegasus XL/Stargazer [2]. This report gives insight into the launch vehicle/carrier aircraft interface, and other unique design choices resulting from an air-launch scenario. From these, a preliminary Functional Block Diagram (FBD) was generated to identify the areas of work and aid scope definition (Figure 3).

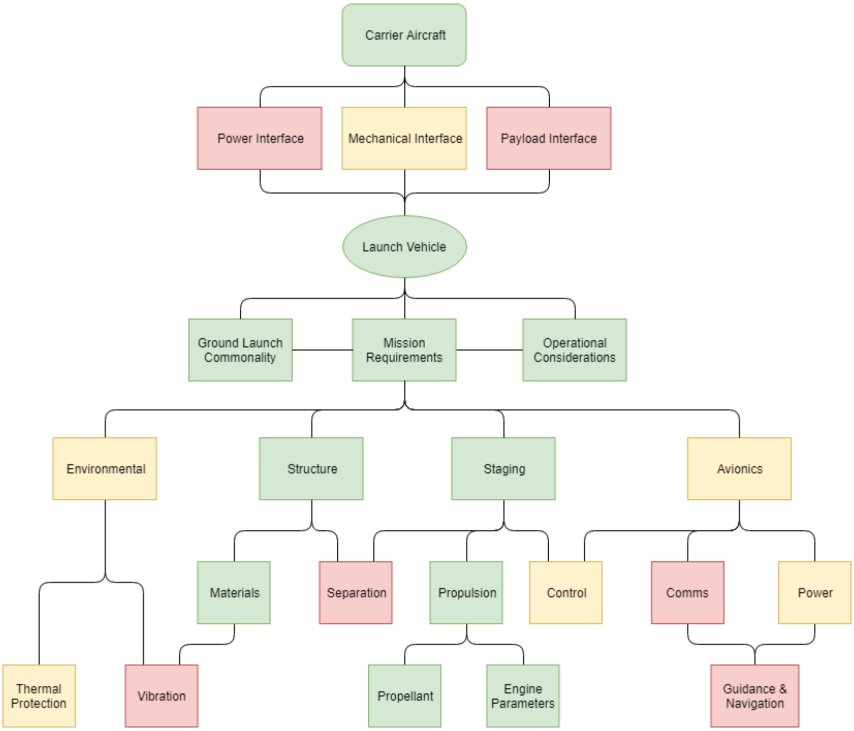

Figure 3: Functional Block Diagram illustrating the scope of the project.

The core design areas of the DMLV are highlighted green in Figure 2; these systems were identified to be most influential at this early stage. The engineering process, in this case, is structured around these key concepts, beginning with a representative mission definition and working down from a system level toward more granular subsystem design tasks. At this stage systems in yellow were considered insofar as their effect on the primary (green) systems. Red systems were disregarded, as their requirements are either driven by properties of primary systems or require resources disproportionate to their effect on the preliminary concept for analysis.

The DMLV design requirements stem from two key goals: to design a system capable of delivering 50kg of payload into LEO from an air-launch, and to achieve the same objective from the ground with the same system, with minimum modification and modular design. A mission was designed to represent the desired capability of the vehicle, against which the success of the DMLV could be measured. Design, simulation and verification were all undertaken with the aim of completing this mission.

System requirements were defined in a trackable hierarchy, including explicitly defined requirements, such as the need for a 50kg payload capacity, implicit requirements and requirements established by the target mission profile. Subsystem level requirements were defined in the same manner as the system-level requirements. A range of solutions for each subsystem, sourced from literature review and state of the art, were measured against the design requirements, and their results compared to identify the most viable solutions. Due to the iterative nature of launch vehicle design, many performance measures could not be quantifiably assessed in the first instance. Qualitative assessment of each solution's expected behaviour, informed by historical information, is the first measure of potential solutions. Solutions judged most feasible by the weighted design criteria were identified and used in system-level trade studies.

The most suitable subsystem solutions were combined to create three complete system concepts. The choice of which subsystems are combined was a balance of high scores against the design requirements and ensuring compatibility between components. With multiple concepts defined, a mass estimation for each was performed through optimal staging and ASTOS simulation. This was a critical step in ensuring that the chosen system was feasible before further design work was undertaken. The most promising system concept was verified with an iteration of mass budgeting using independent Mass Estimating Relationships (MERs). Projected increases in mass were adjusted conservatively, and the new system resized and revalidated. This validated system was then measured against the initial design requirements to ensure that the project goals were achieved.

2. Mission definition

The system level requirements were derived from the selection and definition of a commercially attractive mission, and guided by existing literature. To define what the DMLV should be capable of, the orbits of existing LEO satellites were analysed. The UCS satellite database provides an extensive list of satellites in Earth orbit [3]. This data was filtered to select only satellites with a launch mass ≤ 50 kg in LEO. Of these 582 satellites, 405 travel in a Sun-Synchronous Orbit (SSO) with very low eccentricity. This overriding majority, together with the fact that high-inclination orbits such as SSO require more ΔV as they do not benefit from Earth's rotational velocity, suggests that the maximum-capability design point mission should target an SSO. The altitude and inclination capability of the vehicle was chosen from median orbital properties of these SSO satellites.

Following this process, the resulting proof of concept mission was a launch from Whalers Way (lat -34.944°, long 135.626°), with a circular target orbit of 700 km, at 98.6°. Air launch altitude and airspeed were subject to carrier aircraft performance. Given these targets, a ΔV estimate of 10 km/s was used as the initial design point. Later optimisation would converge on the true ΔV requirement for each system concept.

3. Subsystem Analyses

The results of the system requirements definition process guided the definition of subsystem requirements. A set of requirements was generated for each primary subsystem, derived from literature and the trickle-down of system-level requirements. Many of the requirements were at first stated and assessed qualitatively, and only quantitatively when relevant numbers could be applied from literature or without resource-intensive methods. This allowed a practical preliminary assessment of a large solution space, which was considered essential in a novel design project of this nature.

Subsystem requirements were then prioritised by the use of a pairwise comparison matrix as shown in Table 1. A score of “1” indicates the higher priority of the row’s requirement over the intersecting column’s requirement. The purpose of that matrix was to assign an importance weighting to each criteri for later assessment of design solutions.

Table 1: Pairwise importance ranking of air-launch stage propulsion subsystem requirements.

	Storability	Isp	Bulk Density	Inert Mass	Safety	TRL	Complexity	Cost	Score	% weight	Ranking
Storability		1	1	1	0	0	0	1	5	13.9	4
I_{sp}	0		0	0	0	0	0	0	1	2.8	8
Bulk Density	0	1		0	0	0	0	0	2	5.6	7
Inert Mass	0	1	1		0	0	0	1	4	11.1	5
Safety	1	1	1	1		1	1	1	8	22.2	1
TRL	1	1	1	1	0		1	1	7	19.4	2
Complexity	1	1	1	1	0	0		1	6	16.7	3
Cost	0	1	1	0	0	0	0		3	8.3	6

A comprehensive search for solutions was undertaken, looking at historically successful technologies as well as new and experimental ones. The merits and drawbacks of each solution were explored in the context of the previously stated requirements.

Finally, each of the solutions were scored independently against their subsystem’s weighted selection criteria. Each solution was given a score of 1-3 against each requirement *i*, and the weighted total calculated.

The result of these analyses was a shortlist of preferred solutions to each of the vehicle’s functions, summarised in Table 2.

Table 2: Summary of preferred subsystems.

Subsystem	Component	Preferred Systems	Score
Propulsion	*Upper stages*	1. HTPB Composite	98.1%
		2. HTPB/N2O4 Hybrid	73.1%
		3. RP1/LOX	70.4%
	Ground stage(s)	1. HTPB Composite	96.3%
		2. RP1/LOX	76.9%
Structure	*Tanks/Casings*	1. CFRP	79.4%
		2. Structural Steel	61.9%
	Fairing	1. CFRP	69.1%
		2. Maraging Steel	69.1%
	Unpressurised Structures	1. CFRP	80.8%
		2. Structural Steel	59.0%
Control		1. Actuated fins	89.8%
		2. Thrust vanes	67.6%
		3. Engine gimbal	66.7%
Carrier Aircraft		1. B757-200	86.9%
		2. A330-200	82.1%

4. Concept Generation

A number of potential system configurations were developed through compatible combinations of the preferred technologies listed in Table 2.

The first design choice to be confronted here was the number of stages for each configuration. Recent studies have taken this idea beyond the purely physical problem and incorporated cost and complexity factors into multi-disciplinary optimisations (MDOs) of the optimal staging concept. For payloads of 50kg, three-stage configurations significantly outperform two-stage models in both Gross Take-Off Mass (GTOM) and cost [4]. Extending this concept to the DMLV, it follows that the ground launch configuration should consist of three stages. For a modular design, the air-launch configuration would then be a two-stage rocket, swapping the first ground launch stage for the carrier aircraft. However, studies addressing two-stage air launchers concluded that the use of a carrier aircraft does not provide as much ΔV benefit as a rocket stage, and a two-stage air-launched vehicle is not economically feasible for launching to the target altitude [5].

These discoveries provided two options: reduce the target orbit's altitude or shift to a three-stage design. Reducing the vehicle's capabilities would reduce its usefulness, given how satellites have historically used LEO and SSO orbits. Moving to a three-stage configuration does increase the complexity and cost of the vehicle for the desired capability. However, given the DMLV's goal of modularity and flexibility, it is reasonable that the third stage could be discarded for lower target orbits, maintaining the two-stage cost advantage for suitably low-altitude missions. It was therefore decided that the three-stage approach would be taken to ensure vehicle capability was maintained.

Multiple system configurations were selected for further assessment, based on their subsystem scores and compatibility across subsystems.

5. Concept Selection

Preliminary performance comparisons were performed by estimation of each configuration's GTOM. Each configuration was sized with optimal staging and ASTOS simulation. The results given by this process are the GTOM of each configuration as a function of propellant and staging alone; these factors are so dominant in determining vehicle performance that it is unnecessary to compare auxiliary subsystems at this stage.

Beginning with each air-launch configuration, mass estimates were generated by application of an optimal staging algorithm [6]. Through iterative mass balance, the algorithm distributes propellant among each stage to achieve the ΔV target (10 km/s) at minimum vehicle mass. It takes stage I_{sp} and IMF as inputs, which are properties of the propulsion system used and were sourced from literature. The effective payload used in the algorithm is the defined 50kg payload, plus a 25% allowance for interfaces, plus the fairing mass as estimated by one of many MERs available for preliminary estimations of subsystem masses. This produced a simple estimate of propellant and dry mass of each stage. Using the known bulk density of propellants at their optimum mixing ratio, the volume of propellant in each stage was calculated. The diameter and length of each stage was then derived from the propellant volume, with the aim of maintaining high slenderness (length/diameter ratio) and constant diameter for all stages as far as possible.

This initial guess was provided as the representative ALV to run trajectory and sizing optimisations in ASTOS. The simulation was designed to optimise both the flight trajectory, given the Pegasus launch profile as an initial guess, and the size of each stage. Two optimisations were applied to each configuration; each optimisation is resource heavy and improvements were insignificant after the second pass.

Table 3: Comparison of DMLV system configurations, after optimisation.

Property	Configuration 1 Mini-taur	Configuration 2 Top Scores	Configuration 3 Liquid Propulsion
ΔV (m/s)	8602	8697	8740
Length (m)	7.76	7.34	7.71
GTOM (kg)	3865.6	2384.4	2249.9
Payload %	1.293	2.097	2.222

Of the three configurations assessed, the liquid-fuelled Configuration 3 is the most mass-effective, at just over 5% lighter than the next-best Configuration 2. For a larger vehicle, this would be a great advantage, but for the DMLV this 5% only translates to 135kg of mass saved. Considering the operational and technical complexity involved in using cryogenic oxygen, this small mass saving cannot be considered significant enough to move away from a solid fuel solution. Configuration 2 was selected as the preferred system concept, and chosen as the basis for ground launch booster sizing.

5.1. Ground booster selection

The ground launch boosters were sized similarly to the air-launch stages, using optimal staging. The air-launch stages' mass and dimensions were fixed, and the booster configurations optimised in a ground launch scenario in ASTOS.

Table 4: Booster masses, ASTOS optimisation, pass 2

Property	Serial HTPB	Dual Parallel HTPB	Serial RP1/LOX	Dual Parallel RP1/LOX
ΔV (m/s)	954	953	931	918
Length (m)	1.99	2.84	2.24	3.15
GTOM (kg)	3725.5	3715.7	3617.3	3614.5

Table 4 shows the key dimensions of each booster configuration, with none of the configurations being significantly lighter. The GLV booster(s) will not be used in the vicinity of the crewed carrier aircraft, so are not subject to the same safety and storability constraints as the main ALV stages. As such, there is more scope to optimise the cost of the booster configurations.

HTPB propellant is an ITAR-restricted substance and as such pricing cannot be found [7]. However, the US Department of Defence publishes its standard price points for RP-1 and LOX. Assuming a mix ratio of 2.29 [8], the standard price per kg of the liquid bipropellant is $7.82 [9]. Using the estimated propellant masses of Table 4, the price of each RP-1/LOX combination was found, and the breakeven price point for each HTPB configuration was found. These price points, and the corresponding total cost of booster propellant, are marked in Figure 4.

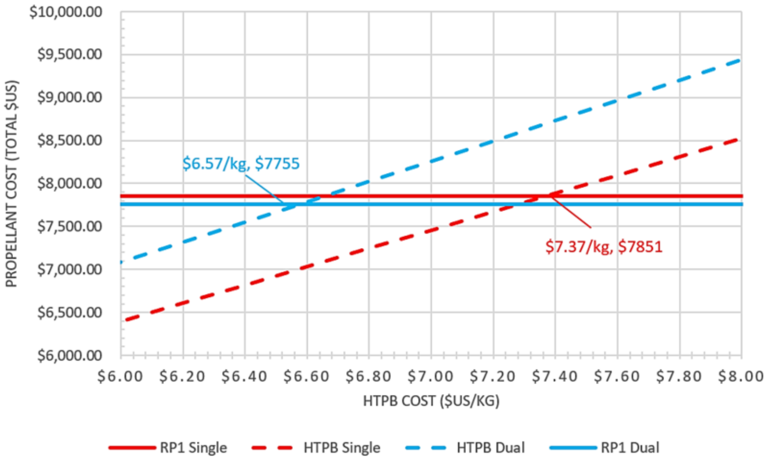

Figure 4: Cost breakpoints for HTPB and RP-1 booster configurations (RP-1 ref cost: US$7.82/kg).

Figure 4 shows that HTPB propellant does not have to be substantially cheaper per kg than RP-1/LOX to be the more cost-effective solution in all cases. Given how extensively HTPB is referred to as one of the cheapest propellants available, it is reasonable to assume that it will surpass the breakeven prices. This is doubly true when accounting for the inert components; turbomachinery, cryogenic insulation and liquid engines are vastly more expensive than the simple solid rocket motor [1] [10].

The dual-HTPB configuration is evidently the cheapest, in terms of propellant. Further investigation is necessary to determine whether the cost advantage holds when accounting for inert components and structure. However, this configuration has several advantages: it maintains the control authority of the ALV first stage fins, has a higher Thrust-to-Weight ratio and adds the potential for modularity and operation flexibility. The dual HTPB booster was selected for the ground configuration.

6. Final Concept Summary

Table 5 and Figure 5 show the selected DMLV configuration. This configuration scores highly against the subsystem level requirements and has been proven feasible by ASTOS simulation.

Table 5: Selected DMLV configuration

		Booster	Stage 1	Stage 2	Stage 3	Payload
Propulsion		2 x HTPB	HTPB	HTPB	HTPB	-
Structures	*Casing*	CFRP	CFRP	CFRP	CFRP	-
	Unpressurised	CFRP	CFRP	CFRP	CFRP	CFRP
	Fairing		-	-	-	CFRP
Control	*Pitch/yaw*	Stage 1 Fins	Fins	Thrust vanes	Thrust vanes	-
	Roll	Stage 1 Fins	Fins	Thrust vanes	Thrust vanes	-
TPS		-	-	-	-	Ablator
Carrier Aircraft		B757-200	-	-	-	-
Average Score		88.44%	87.47%	78.70%	78.70%	74.95%
		System Average Score: 81.65%				

The final mass and dimensions of the DMLV are shown in Table 6, with an additional 100 m/s ΔV as an allowance for drag on the booster and first stages. It is estimated that aerodynamic losses detract 40 - 160 m/s of ΔV from a ground-launch; an addition of 100 m/s to the first ALV stage should be a conservative correction [11].

Table 6: Drag-corrected DMLV with dual-HTPB boosters.

		Booster	Stage 1	Stage 2	Stage 3	Payload	Total
Mass	*Dry (kg)*	88.0	198.4	47.4	8.3	75.5	*505.7*
	Propellant (kg)	686.4	1709.4	401.3	68.5	-	*3551.9*
	Wet (kg)	774.4	1907.8	448.7	76.7	75.5	*4057.5*
	IMF	0.114	0.104	0.106	0.108	-	*0.125*
Dimensions	*Length (m)*	2.99	4.04	1.16	0.49	0.95	*6.64*
	Diameter (m)	0.43	0.58	0.58	0.33	0.9	*1.44m*
	Slenderness	7	7	2	1.5	-	*4.61*
Engine	I_{sp} *(s)*	265	300	313	313	-	-
	Thrust (kN)	58	70	20	5	-	-
	Exit Area (m²)	0.13	0.26	0.26	0.086	-	-
ΔV	*Total (m/s)*	953	3357	3362	2078	-	*9750*
	Proportion	9.77%	34.43%	34.48%	21.31%	-	*100%*
		Payload Fraction = 1.232%					

This design was verified with ASTOS simulation, launching from both air and ground launch scenarios. Additionally, while stage masses were initially estimated from the empirically derived inert mass fraction, as a property of the propellant, a more granular mass estimation has since been undertaken. Structures, components and subsystem masses were estimated with a series of MERs. This second derivation of mass came in under the optimised estimate, suggesting that the optimised solution is both feasible and conservative, and further investigations are justified.

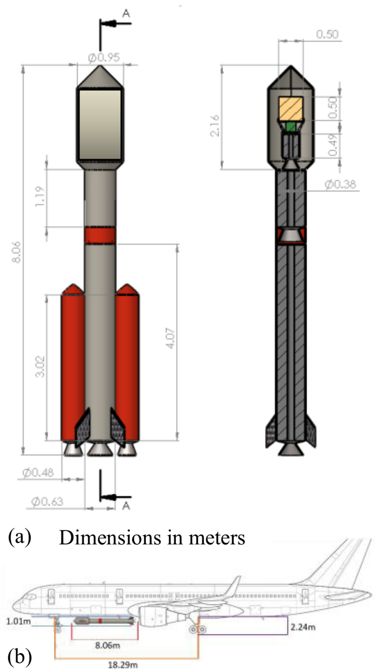

Figure 5: Selected DMLV in ground launch (a) and air launch (b) configuration.

7. Future Work

The goal of this research is to define a framework for future development of a modular launch vehicle for small satellites. This paper, exemplifies the transdisciplinary nature of launch vehicle design. Some discussion on future studies are given below.

Development of an aerodynamics model and simulation should be a high priority. ASTOS can simulate aerodynamic losses, moments and control, but not without a comprehensive study to inform the inputs required. Work performed here is a conservative approximation, but this is the most significant risk factor and will also be necessary for optimised sizing of stages and aerodynamic surfaces. A thorough trajectory analysis, including thrust and guidance optimisation, should go hand-in-hand with this.

The propulsion system has been defined very broadly but is one of the most complex subsystems. Further work should design the propellant grain composition, design and optimise the motor nozzle and, alongside the aerodynamics study, size the motor casing to minimise structural mass and aerodynamic drag while optimising propellant burn.

Structural design has been touched on in terms of key mass contributors, but there has been no detailed design of structural components. A future project should aim to produce fairing and fuselage geometry that can be verified with FEA and vibrational analysis. Particular focus should be put into bending loads incurred by wind shear, which will require the development of the aerodynamics study mentioned above.

8. Conclusion

This project has established the basis for the future development of a dual-capability air/ground launch vehicle, tailored to the unique needs of the exponentially growing small satellite launch market within Australia and beyond. The abstraction of the complex multi-disciplinary design task into a set of functionalities and system requirements enabled a comprehensive but resource-light exploration of the design space. From there, subsystem analyses brought the conceptual design into view. They defined it to a point where verification of the vehicle's success could be performed with simulations and more granular mass calculations. The result is a system framework designed to be built upon in a transdisciplinary manner, where multiple discipline specialists can combine their efforts toward achieving each of the system functions.

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Improvement of Factory Planning by Automated Generation of a Digital Twin

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Abstract. The simulation of processes in production systems is a powerful tool for factory planning. The application of simulation methods within the Digital Factory is becoming increasingly relevant as developments in the field of digitalization lead to more comprehensive, efficient, embedded and cost-effective simulation methods. Especially the integration within a Digital Twin, allows these advantages to be achieved for simulations. Here, the Digital Twin can be utilized for prospective planning, analysis of existing systems or process-oriented monitoring. In all cases, the Digital Twin offers manufacturing companies room for improvement in production and logistics processes leading to cost savings. However, many companies do not apply the technology, because the generation of a Digital Twin is cost-, time- and resource-intensive and IT expertise is required. This paper presents an approach for generating a Digital Twin in the built environment automatically and for utilization in factory planning. The obstacles will be overcome by using a scan of the shop floor, subsequent object recognition, and predefined frameworks for factory planning within the Digital Twin. Here, the effort for scanning the production hall is additional, while the subsequent object recognition, the generation of the CAD model and the simulation model, as well as the factory planning can be to a great extent automated and therefore carried out with a minimum of effort. Therefore, considerable cost savings can be expected here, which more than offset the additional effort for scanning.

Keywords. Factory Planning, Digital Twin, Object Recognition, Process Template

Introduction

Since the digital factory has been recognized as a strategically competitive advantage by the industry, small and medium-sized enterprises as well as large companies are increasingly focusing on digital factory methods and tools [1]. In particular, simulation is a core element of the digital factory and is becoming more important as a result of developments in the area of digitalization [2]. In the field of production and logistics, simulation has been scientifically investigated and established for a long time [3][4][5]. Thus, it supports companies in optimizing logistical targets (e. g. with regard to

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adherence to schedules, throughput times, and costs), as well as in the tasks of material flow planning [6][7].

Today, there are many fields of application for digital models of a production system in a discrete event simulation (DES), such as layout optimization in the shop floor, planning of factories and optimization of production processes. Nevertheless, current studies prove that the use of simulation models for production systems, referred to as *Digital Twin*, in small and medium-sized enterprises is still not standard [8]. The main reasons for this are non-transparent procurement costs, required IT expertise, unpredictable operating expenses and lack of knowledge regarding available simulation tools and application areas as well as the achievable benefits [8][9][10]. In order to overcome these obstacles, an approach is introduced here, which allows a preferably automated generation of a Digital Twin by an intelligent workflow.

The remainder of this paper is structured as follows: Section 1 provides an insight into literature review, followed by section 2, where the parameters for the Digital Twin are discussed. A new concept for simulation modeling and factory planning is described in section 3. The results are presented in section 4, followed by conclusions and outlook in section 5.

1. Background

Industry 4.0, cyber-physical production systems (CPPS) and the Internet of Things (IoT) are current focusses in automation and data exchange in manufacturing, arising from the rapid increase in capabilities in information and communication technologies and the ubiquitous internet. A key enabler for the advances promised by CPPS is the concept of a Digital Twin, which is the virtual representation of a real-world entity, or the physical twin. An important step towards the success of Industry 4.0 is the establishment of practical reference architectures. An architecture for such a Digital Twin, which enables the exchange of data and information between a remote emulation or simulation and the physical twin is presented. The architecture comprises different layers, including a local data layer, an IoT Gateway layer, cloud-based databases and a layer containing emulations and simulations. The architecture can be implemented in new and legacy production facilities, with a minimal disruption of current installations. This architecture provides a service-based and real-time enabled infrastructure for vertical and horizontal integration. An intelligent workflow is an important means for implementation of such infrastructures [11].

By using a Digital Twin, enterprises from different fields are taking advantage of its ability to simulate real-time working conditions and perform intelligent decision-making, where a cost-effective solution can be readily delivered to meet individual stakeholder demands. Most approaches today lack a comprehensive review to examine Digital Twin benefits by considering both engineering product lifecycle management and business innovation as a whole. The systematic review further identifies eight future perspectives for Digital Twin, including modular Digital Twin, modeling consistency and accuracy, incorporation of Big Data analytics in Digital Twin models, Digital Twin simulation improvements, VR integration into Digital Twin, expansion of Digital Twin domains, efficient mapping of cyber-physical data and cloud/edge computing integration [12].

Factory planning is a complex process chain which involve several teams and individuals. The collaboration of various persons with different points of view can lead to conflicts and misunderstandings due to, for instance, differences among domains' vocabulary. One solution to solve this problem is to formalize the technical terms of each domain and to create correspondences among concepts defined within each domain. This can be achieved by defining an ontology of the domains. An ontology allows to represent concepts and relationships between these concepts that can be used to both infer implicit knowledge and to check the consistency of the domain definition by resorting to an inference engine [13].

Beside collaboration, another key factor in modern product design is the ability to reuse existing knowledge in design, products or processes. In this scope, one major change during the last years is the democratisation of Knowledge-Based Engineering (KBE). KBE is a large field at the crossroads of Computer-Aided Design (CAD), process planning, factory planning, artificial intelligence and programming [13]. A cross-domain, downstream approach promises most benefits.

Knowledge-based engineering templates are intelligent models or features that are able to store design intent as well as product and process knowledge. This can then restitute the knowledge by adapting them to design contexts, i. e. environments where the template is used, such as a car assembly model or a wing model. The following terms are often used: intelligent template or object-oriented template [13]. Templates can be used both for the automation and synchronization of processes.

A process template represents a structured sequence of tasks related to the CAD-system elements based on the underlying business process which significantly exceeds the border of the design process. A CAD-based process template controls the information flow between the CAD elements and triggers multiple actions based on user interaction or dedicated events, e. g. instantiation of other templates. A process chain template extends this scope to connect different domains (e. g. design to manufacturing) which is important in context of Digital Twin [14]. A template is able to store comprehensive, complete information about the evolution of the formal problem modeling and the corresponding auxilary data.

Templates can be used in the assembly modeling of complex products, where it is not unusual facing an explosive growth of assembly relations, or called combination explosion. Through integrating object-oriented methods with the knowledge template based modeling, it is possible to deal with the complexity of the assemblies of large-scale products. As such, the templates with various assembly relations can be defined for complex products; constitutive parts or subassemblies in a product structure are defined as object classes; their features can be encapsulated, and defined or modified freely via the parameters of object classes to meet the requirements of a specific instance. This method supports reusing knowledge and simplifying assembly modeling of complex products such as aero-engines [15].

The generation and instantitation of intelligent process templates set several strict pre-requisites to process constituents: clear process definition [16], proper data structure [17], high data quality [18], high-level interface [19], deep modularization [20], and a stable and reliable control environment [21]. Furthermore, a template must be maintained over a long period of time and can become subject of intellectual property theft [22]. The main gains of template use are the process acceleration, lower operating costs, improved traceability and error avoidance.

A particular challenge consists of generation of a Digital Twin in a built environment where the necessary data are not available and must be acquired either from physical object or analog documents. With the regard to a previous publication [23], where the approach for automated object recognition is described, we will concentrate here to the last step: acquisition of models in the planning step by using a high-level process automation by intelligent workflow.

2. Generation of a Digital Twin

To generate a Digital Twin as automatically as possible, the method presented here applies fast scans of the shop floor and subsequent object recognition using artificial intelligence algorithms. Here, the production layout (e. g. size and location of objects) and production logics, such as machine types and transport routes, are captured automatically and mapped to scale in digital simulation models. For efficiently generating a Digital Twin, three different input sources can be distinguished, as shown in Figure 1 [24]:

- Group A parameters is obtained directly from a scan (e. g. machine geometries). Different scanning methods, such as laser scanning or photogrammetry, are utilized here.
- Group B parameters require additional object recognition (e. g. machine types). To record these parameters, a reference database of Computer-Aided Design (CAD) models is necessary in addition to the production scan. A matching of the scanned object with the CAD models of the reference database provides the required input parameters for the Digital Twin.
- Group C parameters, contrary to the others, cannot be captured generically or automatically. They are determined on a company-specific basis (e. g. machine times). Appropriate forms are developed for the acquisition of this parameter group, so that a survey of typical parameters can be carried out and this process can be performed with the least possible effort.

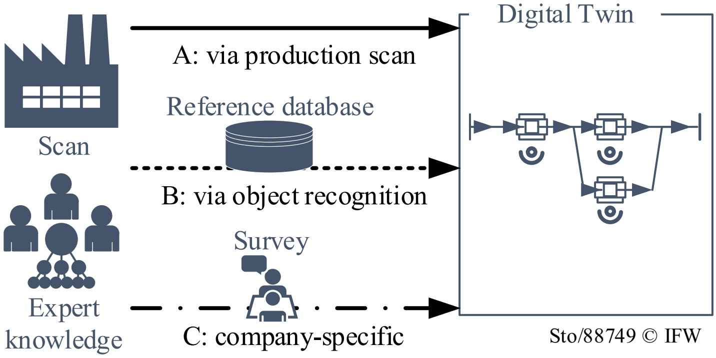

Figure 1: Overview of the automated generation of the Digital Twin [24]

For the defined parameter groups, specific data is required. The parameter definition is derived from factory planning, especially material flow planning, investment planning, and capacity planning, in order to consider their requirements and to narrow down the subject matter. Thus, long-term planning processes and analyses of the existing system are both considered, this wide-raging selection is suitable as a basis to generally determine the required parameters. Objects such as machine tools, workstations, workers, conveyors, and load carriers must be built into the simulation model. In order to recognize and create these objects sufficiently for the Digital Twin, the three parameter groups mentioned above are used. For each object, there are different parameters that are relevant for the simulation model. This will be shown in more detail in the following example.

First, the parameters that can be obtained directly by the scanning process are determined. For the object "machine tools", these parameters consist mainly of the spatial information. Since the simulation model is not able to process detailed CAD data, the dimensions of the bounding box are used as an acceptable simplification. Further useful parameters are spatial relations to other objects of the production system.

For the second group of parameters an object detection is connected. By a similarity analysis of the spatial information with an external database, further information can be added to the model. Object recognition makes the stored information available for the Digital Twin. For the example of machine tools, different data can thus be provided. In general, all generic properties of machine tools are conceivable, such as power, machining area or capacity. This procedure can be applied to machine tools, as well as to other objects, such as workstations or transport equipment, to store comprehensive information in the external database and thus provide it to the Digital Twin.

The third parameter group, the company-specific data, cannot be captured with a scan and subsequent object recognition. For the consideration of machine tools, this group includes: The link logic to upstream and downstream processes or machines, processing, setup, distribution and recovery times, setup information, downtimes and their distribution, shift calendars and availability times. Additionally, specifics of the respective simulation software may have to be determined, e. g. classifications of the resource type or reference periods for statistical recording. While the first two parameter groups can be recorded nearly automatically, the third group requires manual effort. By developing forms and interviews, this process can still be made efficient. It is also examined to what extent standardized interfaces to IT systems can be pre-defined in order to access company-specific data.

A total of 321 parameters for the Digital Twin were identified and a parameter group was assigned to each of them. In addition, a description of the parameter, a label for the data transmission, whether it is a mandatory entry, a data type, the requirement for updating or continuous recording and an assignment to the described use cases were compiled for documentation purposes. With this, it is possible to develop a data interface to a simulation software to automatically generate a model, which will be further described in the following.

The approach for an automatic generation of a Digital Twin consists of three fundamental steps:

1. Scanning the production system to obtain a point cloud
2. Modelling with the objective of creating a mock-up
3. Simulation modelling for the generation of a Digital Twin

Figure 2 shows an overview of the approach by integrating the three steps mentioned above into a data model. Here it becomes apparent how the three parameter groups relate to the three process steps. A detailed description can be found in [24]. For step 1 a detailed point cloud can be generated by laser scanning. Here, the further processing through object recognition and the subsequent modelling up to the Digital Twin gains a sufficient basis. Further information on the scanning process was published in [23]. The modelling, step 2, needs to be heavily supported by object recognition to save time and effort. To achieve this, a database is required, in which CAD models of suspected objects are stored. Scalability is an important requirement for this approach, because theoretically each of the infinite built objects needs to be recognised. Further object parameters are stored in an external database and provided for the last step. The technical procedure and a description of the algorithms used are presented in [25]. In step 3 this information is used for the simulation modelling of the Digital Twin. An interface is used in order to retain the class structure when transferring information from CAD to the simulation software. The expert knowledge and the company-specific information of the production system need to be acquired by forms or expert interviews and inserted in the simulation modelling process. It is also conceivable that data could be taken directly from IT systems. This third step will be discussed in more detail below.

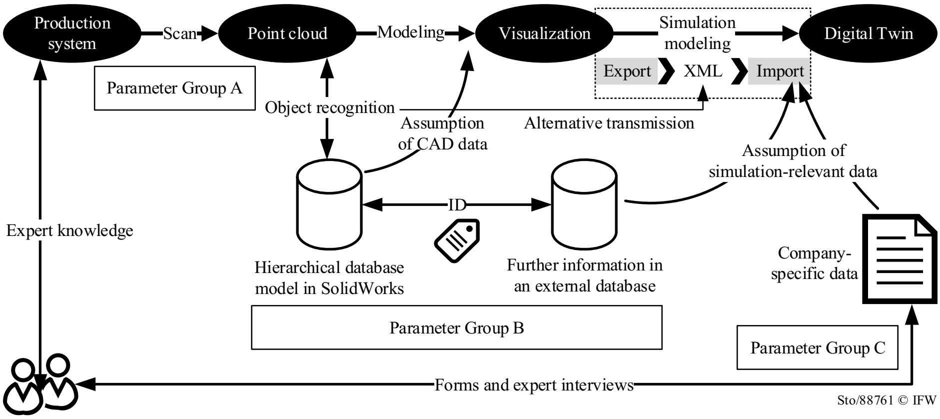

Figure 2: Overview of the overall process

3. Simulation modelling

The simulation modelling receives as an input the model data from the object recognition, in particular the spatial information of the object as well as the specific properties of the objects. For this purpose, a format is required that distinguishes between objects, that means that it is object-oriented, platform-independent, and is open-source, so that an adaptation to the concrete requirements can be carried out. This format is provided by the XML schema and is therefore used for the project [26]. Accordingly, the input is transmitted in an XML file.

Two cases can be distinguished here: On the one hand, the XML file can be generated directly from the object recognition process. This approach is applied in the project, because it allows to achieve the highest performance, without additional manual affort, and to avoid transmission errors. On the other hand, the XML file can also be generated by exporting the CAD model. This approach was also developed in the project, but at this point there remain the mentioned performance and transmission problems. However, this second procedure still has its justification, since the simulation modelling can be used with already existing CAD models.

XML is a format that allows data to be stored in text files in a structured manner [26]. In the present case the XML format was used as CAEX. This format specification provides requirements for the structure of the XML file. For the presented each data item of the XML file represent an object in the model. Here a distinction is made between the input parameters already described, such as machines, conveyors or transport equipment. Every item is assigned attributes. These attributes can be different for various objects, depending on the properties of the objects. For example, processing time can be stored for machines, while for a conveyor belt the length is stored in the XML file. However, it is also possible to store the same attributes for both example objects mentioned. For example, the locations in the model are transferred here in X and Y coordinates.

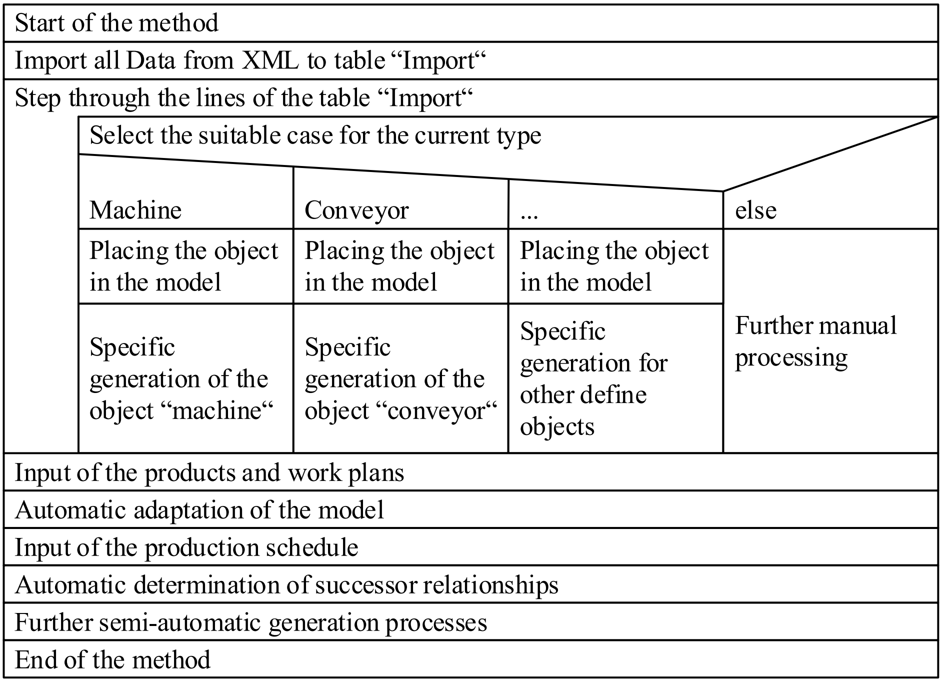

Figure 3: Representation of the simulation modelling process with a Nassi-Shneiderman diagram

The import of the XML file to the simulation software is structured in such a way that all values from the XML file are first written into an internal table of the simulation software. This procedure is useful because it reduces the calculation time. In the program code, this import is autarkic to the model creation. The internal table in the simulation software corresponds to the structure of the XML file, i.e. all attributes correspond to columns and the single objects are listed line by line.

The model construction is carried out by an autarkic method, too. For this, the internal table created by the import is step by step run through. Each line corresponds to an object of the model, so that a simulation module is generated here in each case. In the first step, a case analysis is carried out, which depends on which object type is given. This means that a different generation process is carried out for a machine object type than for a means of conveyor, for example. This corresponds to the differently stored parameters, as mentioned above. In a second step, a part of the model is then generated for each object. For this purpose, the item data is first used to place the object. This data must be scaled to the size of the simulation model surface. Then the specific data is added to the generated module. As already mentioned, these differ depending on the type of object.

Once the method has been completed, a rudimentary model is obtained. User input or a export from other IT-Systems, for example from a manufacturing execution system (MES), is required for further automated generation steps. For example, an additional method has been developed that implements predecessor and successor relationships in the model based on the production schedule. For this, however, the production schedule is required first, which cannot be determined by the scan and the subsequent object recognition. In order to design this process as efficiently as possible, predefined tables have been stored in the model, which can be filled either with minimum effort by experts of the production system or by a defined export. Figure 3 summarises the process again. By the end of the method or the connected methods after user input, a conditionally operable simulation model is obtained, which can be extended to a Digital Twin.

After the simulation model has been built, factory planning measures can be applied. In the approach presented here, these are also predefined and can be executed with a minimum of manual effort. For example, the value stream of the products can be displayed directly in a Sankey diagram. In this case, only the interpretation by experts is an additional manual effort. Another example is the bottleneck analysis, which can also be performed automatically. Here the bottleneck station is identified by considering the proportion of value added in relation to the waiting proportion. These values are generated by a simulation run. In this context, further examples of measures in factory planning are investment planning, inventory management and layout planning.

4. Results

The procedure shown was applied in an example scenario. The following section summarizes the most important findings.

The export method, with which the creation of the XML file can be performed automatically, was programmed in a macro for SolidWorks. It is open source and can be therefore downloaded from [27]. The macro is written with the Visual Basic for Applications (VBA) programming language and must be triggered manually in SolidWorks while a model is open. The XML file is the direct result of the macro. An XML file in CAEX format is available, which contains the objects of the model and their attributes as explained. The import was implemented in the software Plant Simulation. Here an internal program function was used to transfer the internal table with the data from the XML file. Such predefined commands are often found in other simulation software, which again emphasizes the advantage of using XML. The program code for generating the model is also published and can be found in [28].

As only one example scenario has been carried out at present, it is not possible to specify what effort can be saved by the method. However, it can be concluded that the effort for scanning the production hall is additional. This can take one to two working days, depending on the size of the hall. The subsequent object recognition, the generation of the CAD model, the export from the CAD software respectively the import into the simulation software and the first rudimentary model generation can be automated and therefore carried out with a minimum of effort. The subsequent finalization of the simulation model is supported by further automation and predefined templates respectively interfaces. Therefore, considerable cost savings can be expected here, which more than offset the additional effort for scanning.

5. Conclusions and Outlook

The article presented here has shown how the generation of a Digital Twin can be achieved efficiently and with several automated steps. It was explained how required input parameters were derived from the targeted use cases. Afterwards the whole process was explained in detail. This novel process reduces the effort to generate a Digital Twin, so that the utilization can be beneficial for a multitude of companies, in particular SMEs.

Our focus was set on three of the aforementioned eight future perspectives for Digital Twin: modular Digital Twin, modeling consistency and accuracy, and Digital Twin simulation improvements. At first, we have divided the DT into several modules according to the factory structure, thereby achieving greater interchangeability and repeatability.

By generating and using pre-made CAD models of the machines and the devices from a library, the highest requirements for model consistency, quality and accuracy could be met, which are comparable with the remastering of the CAD models. Furthermore, this approach opens the door for a cooperation with the manufacturers of the factory equipment and the vendors of object libraries as well.

The use of intelligent templates on the one hand achieved a high degree of automation and on the other hand created the possibility of expanding the simulation environment (e.g. ergonomic studies).

Finally, a clear process definition combined with a high-level interface facilitates a stable and reliable control environment. Based on an highly accurate object recognition, our approach provides a significant process acceleration, improved traceability and error avoidance at lower operating costs.

In addition to the technical extensions, the procedure must be validated in further applications. Only then can it be finally determined how much effort can be saved by applying the procedure.

Acknowledgement

The authors gratefully acknowledge, that the presented method is a result of the research project “DigiTwin - Efficient generation of a Digital Twin for manufacturing” which is granted by the Federal Ministry of Education and Research (BMBF) under the funding measure "KMU-innovativ: Produktionsforschung" (funding code 02K18K003).

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Development and Construction of LED Lamp Power Supply Cover Based on the Design Concept for Injection Molding

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Abstract. This paper presents multistage process and complexity involved in construction design from initial planning to final CAD models. The purpose of the presented project was to design a cover for the power supply for the LED lamp manufactured by the company based on various design concepts. The work involved in this project was divided into 2 stages. Stage 1 involved construction of the cover using one variant of the design concept. Stage 2 presented a second variant of the design concept. Many design modifications resulted in variety of models adhering to technological objectives and external aesthetics (verified by designer). This paper underlines the extent and complexity of construction design with multiple adjunctive and interrelated stages, where the use of technological innovations in engineering can speed up construction.

Keywords. injection molding, guidelines to plastic product design, construction process, industrial desing project, CAD design, FEA simulation, FEM

Introduction

The paper presents complex and multistage process of construction of an everyday use object (as identified in the title) from initial design to final CAD models. The stages of creating a new product covered various aspects of technology and design concept, and the most appropriate variant of the concept is repeatedly a key factor in accepting the proposed solutions. The paper describes interwoven relationship of two fields: engineering and industrial design by widely established co-operation between constructor-designer roles. The important factors applied in this project were technological concepts of high pressure forming (injection molding). Its development is the fastest growing branch of processing elements from thermoplastics [4]. It allows to create any shape in a relatively short time. The greatest advantage of this technology is the ability to produce a completed product directly after taking it out of mold [5]. However, the key aspect of effective injection molding is the process of building of a manufactured part. It is important for the designer to understand the molding process, its capabilities and its limitations. Factors such as wall thickness, draft to parting plane and radius of sharp corners determine the success of this production technology. Multiple publications and industry guidelines are available to explore technology of plastic part design [6,7,8,9,10].

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1. Methods

The project involved multistage (iterative) process shown in Figure 1. Like in every research, verification of the process is vital. This project used a discussion panel where different conceptual variation between construction group and industrial designer were debated. Ideas, comments and observations regarding design concepts and construction variants were exchanged. Frequently, during the discussions new ideas about shape or production process were identified (illustrated further in the article). The variability of opinions reflected the mix of professionals included in the manufacturing process (from mechanical to artistic approach). To achieve the final products several dozens steps were undertaken. They included tools such as 3D CAD design, numeric simulation FEA and visualisation tools to present realistic image of CAD models.

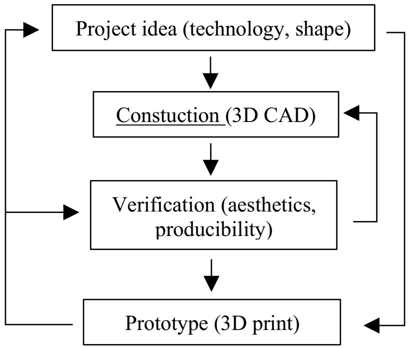

Figure 1. Multistage process of the project.

2. Aim

The aim of the project (which is presented in this paper) was to create the construction process of power supply cover for LED lamp, model *Tablet* produced by company NC.ART (Figure 2), using the design concept. The cover was to meet all the design and construction criteria identified by the NC.ART, including the production technology (plastic injection).

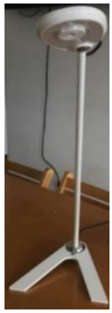

Figure 2. Image of NC.ART LED lamp, model *Tablet*.

3. Origin of the project

Issues discussed in this article are the results of working relationship between the Warsaw University of Technology and NC.ART company [1]. The initiative was to create own cover for the power plug for existing LED lamp (Figure 2) by the NC.ART company. At the start the NC.ART company presented their progress to date including hand-made power supply cover prototypes (Figure 3). However, after drive assembly (Chinese production) the light was flickering which was unacceptable for the final product. Therefore, the company directors decided to create customised cover for the AIMTEC AD/DC LED driver as the universal ones did not meet the shape criteria. At this point the authors of this article were approached.

Figure 3. Hand-made prototypes of power supply cover.

Figure 4. Driver AIMTEC AMEPR5,

4. Power supply construction criteria

During initial talks NC.ART company identified their construction criteria. Technological aspects of the cover construction were as follows:

- division of the cover into parts and to identify parting line of mold (with recommended use of two-plate mold),
- method of connecting the part of power supply cover,
- define internal electrical connections,
- method of preventing the cable from being pulled out,
- ribs strengthening the construction,
- localising the components: an electric plug (Figure 5), the driver AIMTEC (Figure 4), a cable strain relief (Figure 6).

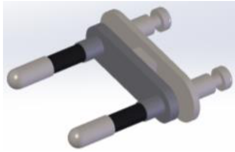

Figure 5. Electrical plug.

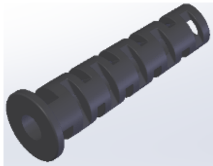

Figure 6. Cable strain relief.

Construction criteria of the external shape of the cover were based on two design concepts – concept I (Figure 7) and concept II (Figure 8). They were created in the CAD geometrical model, which was developed by the design on the basis of internal parts dimensions (for example: electrical plug – Figure 5).

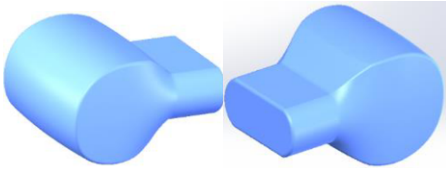

Figure 7. CAD geometrical model concept I.

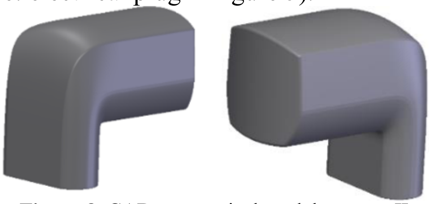

Figure 8. CAD geometrical model concept II.

5. Implementation

The construction of the project was carried out by the two mechanical engineers whereas NC.ART designer was responsible for the design concept. Regular meetings between the group and the designer, where the CAD models were discussed, ensured quality and sustainability of the work.

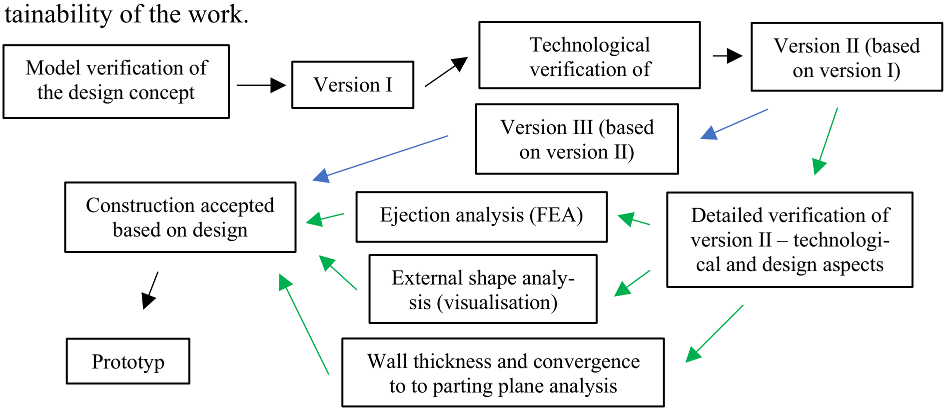

Figure 9. Design concept I step by step creation.

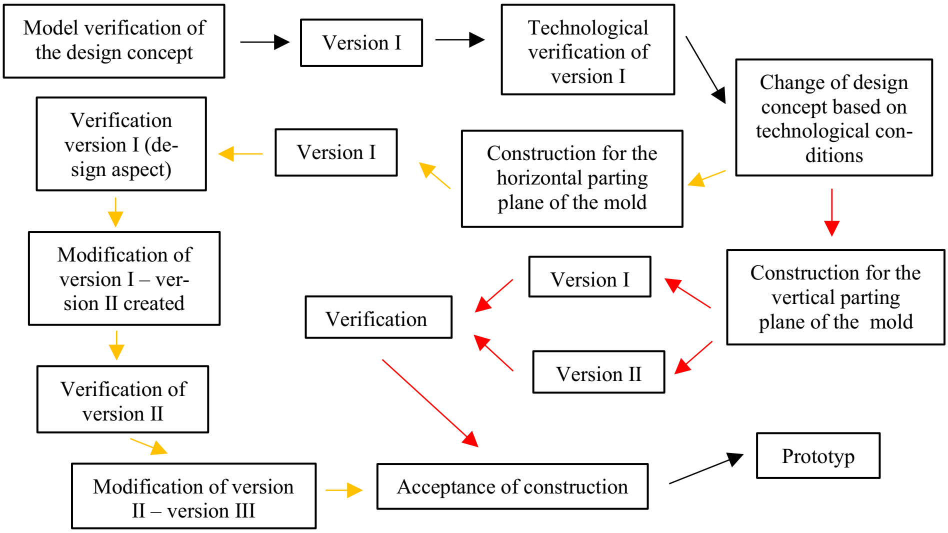

Figure 10. Design concept II step by step creation.

Variety of solutions for both concepts were created simultaneously. Nevertheless, to present systematic construction process of each they are described separately. This way it is possible to explain the multistage design process and the workload of creating the construction from the design concept. Figure 9 and Figure 10 illustrate the steps taken according to each concept, whereas more detail description of their key elements are presented further in the article.

5.1 Concept I

Initial project, the CAD model of design concept I, was verified by the designer through measuring all sketches and operations utilised during the build. This enabled the use of SolidWorks parametrics during further construction. In version I of concept I wall thickness was identified based on overall dimensions of the model. Then parting plane of the form was chosen and all construction elements specified in the initial criteria were created. Figure 11 presents the version I of the cover.

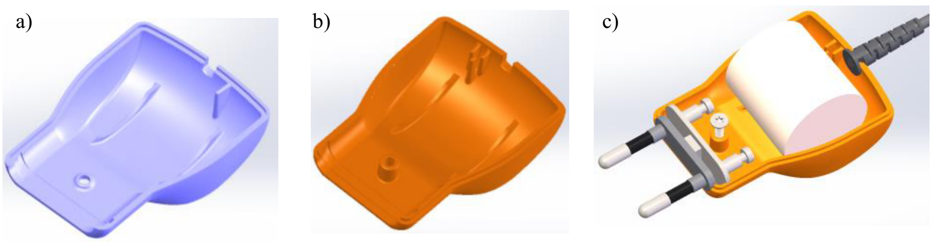

Figure 11. Cover version I of concept I. a) lower part, b) upper part, c) internal elements of the cover.

The next step was to verify the power supply cover using technological testing including wall draft to parting plane of the form as shown in Figure 12. It became apparent that the construction did not meet the minimal draft angle (equal to 1°) which is vital to successful ejection of a part from the mold. Too many construction errors would not deem the form suitable for designer review, therefore, modification of version I was undertaken. Technologically corrected version II is presented in Figure 13.

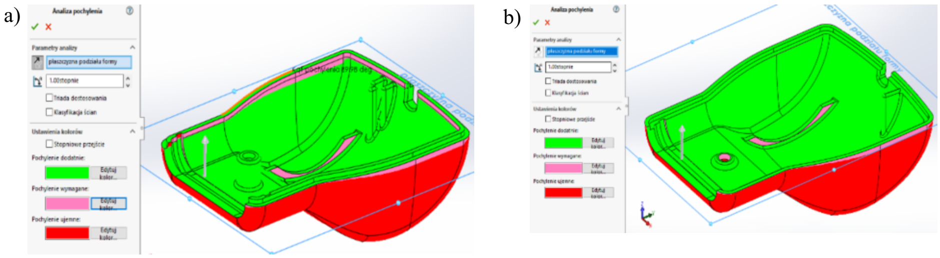

Figure 12. Analysis of draft to parting plane of the form version I a) part A and b) part B. The areas of a draft angle of 0-1° are marked in pink; all other areas of a greater draft angle are marked in green and red.

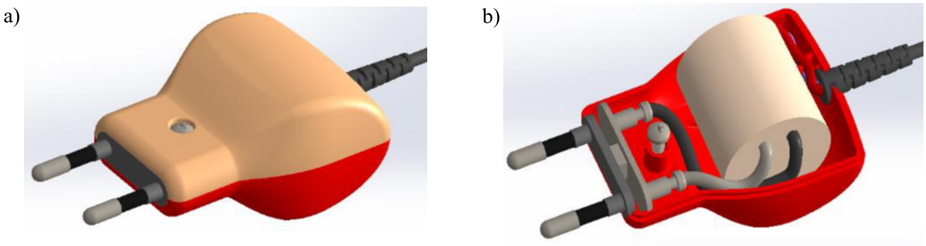

Figure 13. A) Concept I version II, B) A view of all power supply cover including all internal parts.

During construction of version II internal placement of electrical cords was taken into consideration. This identified that the internal space of the cover will have to be increased, as the clearance between internal elements was too small. Finally, the model met all construction criteria and further detailed technological testing of concept I version II was undertaken. The analysis included:

- injection of plastic into form volume analysis using FEM,
- walls draft to parting plane keeping minimal angle,
- wall thickness in plastic part,
- model visualisation with actual facture, colours and light reflection.

Injection analysis also contained the evaluation of size of thermal deformations (warpage) after ejecting parts from the mold, Figure 14 incorporating finite elements method. Mesh surface was used in view of thin-walled model and degree of precision in calculations.

Further analysis concentrated on analogical verification of model's wall draft to parting plane of two-plate mold as shown in Figure 12. Additionally, wall thickness verification identified lack of any abnormalities with uncontrolled localised thickness changes.

At the end of verification of version II visual effect and quality of surfaces by reflections was evaluated. After technological testing mechanical engineers used photo-realistic visualisation system to present the final result of version II to NC.ART designer (Figure 15).

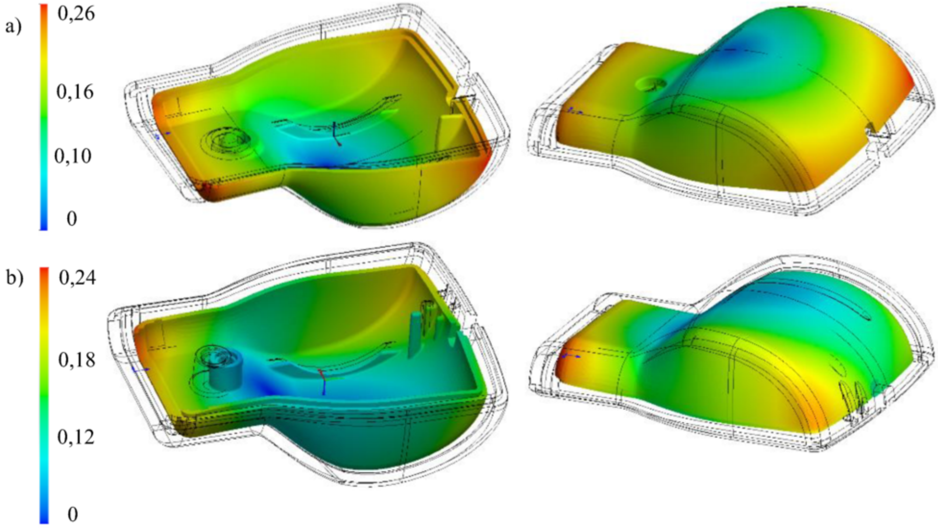

Figure 14. Accidental distribution of deformations (in X, Y, and Z axis) of part a) A and b) B of the form in [mm], scale 20xgreater after cooling down to 30° C. Sketch in black represent the model after taking it out of the form, colours though present it after thermal cooling.

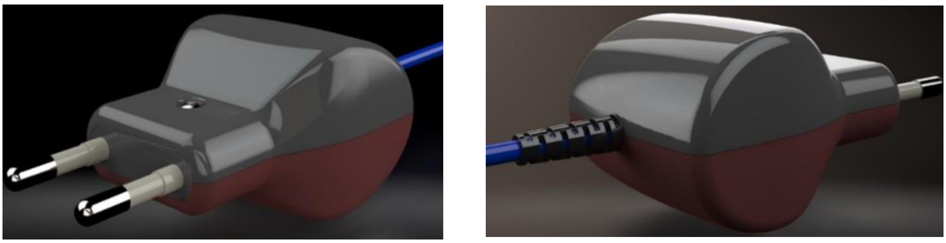

Figure 15. Realistic visualisation of version II model.

The model was positively received, with minor suggestion of moving the screw placement to the back. It was taking into consideration possible thermal displacement during injection molding process (Figure 14.). Additionally, the change would not only add to visual value of the model (Figure 16), but also improve functionality of a cable stoppage. Considering vast and long experience in the industry designer's suggestion was implemented and version III of concept I was constructed (Figure 17).

Figure 16. Screw placement change (draft by T. Rudkiewicz, NC.ART).

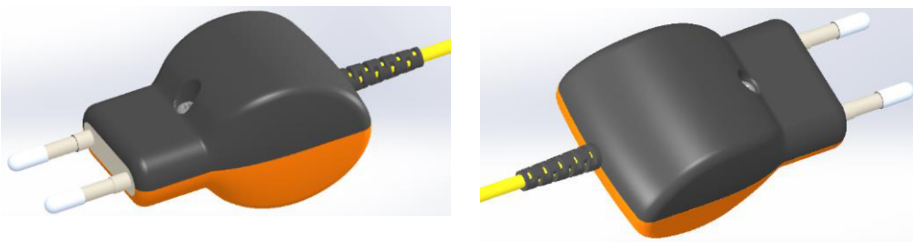

Figure 17. Version III based on version II.

As the results of the work on concept I were satisfactory for both sides its construction was finilised on version III. NC.ART would produce prototype of version III using rapid prototyping (FDM) method based on which further improvement would have been made.

5.2. Concept II

Work on concept II (Figure 8) started by verification of the initial model. Version I was then created incorporating all elements according to the technological criteria. Figure 18 illustrates the proposed cover. The results was presented to the NC.ART designer. During the verification process it was decided that proposed parting plane was too complicated. Despite adhering to the shape suggested in the design concept, the construction cost of this form would have been to high. Arbitrarily, the decision was made to change the division of the mold as seen in Figure 19. However, it became apparent that there was a problem with convergence when adjusting version I to the new parting plane (Figure 20). Therefore, due to technological and economic factors it was not possible to create the shape according to initial design concept (Figure 8). Unfortunately, the designer did not present detailed criteria for external shape. Hence, the mechanical engineers had to propose alternative cover shapes of version I horizontal and vertical parting planes. The results of construction in horizontal and vertical parting forms are described separately below.

Figure 18. The power supply cover version I of concept II including internal elements.

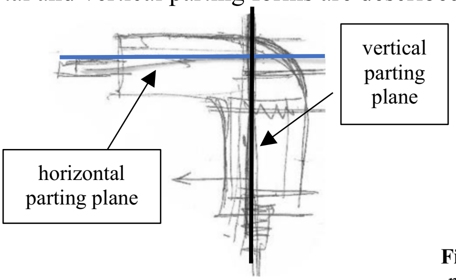

Figure 19. Proposed parting form of concept II (draft by T. Rudkiewicz. NC.ART).

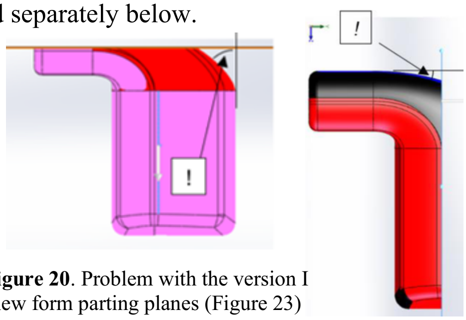

Figure 20. Problem with the version I new form parting planes (Figure 23) convergence.

5.2.1. Horizontal parting plane

In the first version of this variant construction elements, such as: strengthening ribs, lip and groove to assembly both parts of the cover, boss and hole for screw were created. More detailed technological aspects were also taken into consideration, but these are not included in the article. The external shape of version I (Figure 21) in this plane was presented to the designer. Unfortunately, the

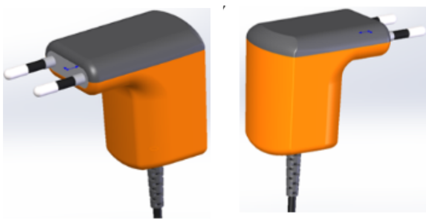

Figure 21. Version I for horizontal parting plane of the form.

back part did not meet their expectations and illustrative sketch of the cover was presented by the designer, see Figure 22. On its basis small adjustment was made in the CAD model to create plane that would crop the back part of the cover. It enabled any shape change to this part. Version II was created on the basis of above mentioned corrections (Figure 23).

Figure 22. Version II draft drawing (auth. T. Rudkiewicz, NC.ART).

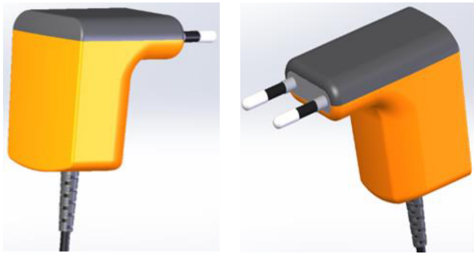

Figure 23. Power supply cover version II.

The designer accepted the shape of version II (Figure 23). At this stage it was proposed to create the shaped element – a snap-fit – to connect two parts of the version II cover (Figure 24). Considering endurance issues and guidelines presented by Bayer Material Science [12] analytical calculations were taken to choose the snap-fit dimensions. Version III as a modification of version II is presented in Figure 25.

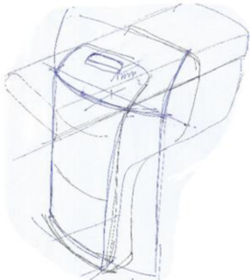

Figure 24. Snap-fit draft drawing (auth. T. Rudkiewicz, NC.ART).

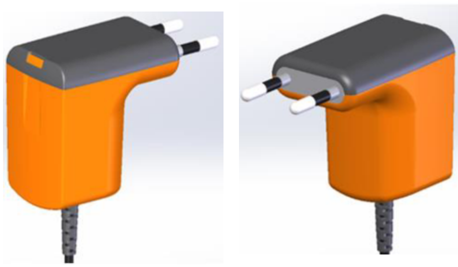

Figure 25. Version III for horizontal parting plane of the form.

At this stage both models of version II and III were accepted by the designer and met all technological criteria. The company management found the use of snap-fit in version III very interesting, which was not at all considered at the start of the project.

5.2.2. Vertical parting plane

Figure 26. Version I of vertical parting plane of the form (Figure 23).

First proposed version for vertical parting plane of concept II is presented in Figure 26. For this solution it was decided to use snap-fit in the back part of the cover, which would strengthen the blocking elements to prevent cable being pulled out. During verification meeting proposed cover (Figure 26) met designer’s expectations, despite lack of hints of its external shape. Additionally, one of the mechanical engineers suggested to change the screw for a few bigger snap-fits to connect two parts of the cover. It was thought that the cost of construction will be reduced as smaller amount of plastic would be used during production. However, the snap-fit solution would significantly modify the external shape of version I (Figure 26) to ensure visually attractive integration of the snap-fit into the cover. Figure 27 presents initial sketch of this solution. All requirements of this solution created exceptional construction challenge, the effect of which is presented in Figure 28. As the NC.ART designer accepted version II for vertical parting plane of the mold the construction work was completed at this stage.

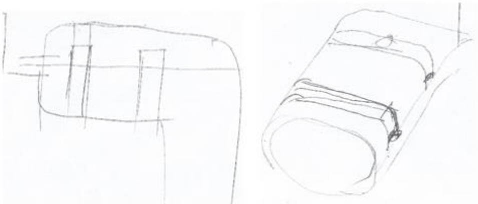

Figure 27. Draft drawing of snap-fit in version II (auth. T. Rudkiewicz, NC.ART).

Figure 28. Version II of vertical parting plane of the form.

6. Conclusions

Development and construction of a new product (a small size power supply cover for LED lamp) involves many iterations during design process and depends on collaboration of many people from different industries. It is more pronounced when mutual interests (designer - constructor), openness for new ideas and changes, thinking outside of the box and exploring new routes of development (not sticking to established paths) are present. This project required co-operation and understanding between two different approaches to construction (creating) issues: engineering and design. As presented in the article several wrong suggestions or even mistakes are inevitable parts of such project. However, those mistakes and knowledge and experience of each team member contributed to a consensus and resulted in creation of interesting useable forms for the power supply cover. The aim of this project was to illustrate the complexity and diversity of developing construction even of a seemingly simple object, such as a power supply cover. It is especially noticeable when the best construction and technological aspects are to be met according to the company's design requirements. The closing opinion is worth mentioning that the continuous development of the new model is still ongoing; it is a long and tedious process.

Acknowledgement

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Morphic Arrangement of High Flexibility and Aspect Ratio Wing

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Abstract. Morphing of aerodynamic surfaces or conformal shape adaptation of aerodynamic surfaces can be used to control aircraft, utilized similarly as in nature, where insects and birds deform their wings to achieve a wide range of flight conditions. Morphing of wings has the potential to bring numerous advantages in flight performance in comparison to a rigid, conventional solution, that utilizes stiff aerodynamic surfaces. Reduction of parasitic drag due to the lack of gaps between the various moveable surfaces is one of them. Even so, a wing whose sections are able to deform independently or conform can better adapt to wide range of flight conditions than a rigid solution, or a solution based on conventional aerodynamic surfaces, such as flaps and ailerons. Additionally, the conformal shape adaptation or morphing of aerodynamic surfaces may lead to a potentially reduced weight and mechanical complexity, which may be achieved by utilizing wing deformations directly in the structure instead of connecting conventional actuation devices to the system. The aim of this paper is to propose a morphic arrangement of a high flexibility and high aspect ratio wing, that could be utilized in High Altitude Long Endurance aircraft, where the efficiency of the design is of utmost importance. A significant reduction of parasitic drag and reduction of weight is a promising basis for pursuing morphic and conformal shape adaptation designs. This paper qualitatively explores the space of morphic arrangements and conformal shape adaptation designs and utilizes inventive approaches to check and identify designs that may be promising. A wing design is proposed, that utilizes morphing of wing and conformal shape adaptation.

Keywords. morphing wing, high aspect ratio wing, high flexibility wing, aircraft control

Introduction

The idea of a morphing wing arrangement is a direct conflict with structural requirements, however as alternative methods for control of aerodynamic surfaces were developed, new materials and tools for optimization became available, such designs are becoming more popular and an active area of research. Morphing technologies are an area of interest due to the fact that they offer lowering of consumed power, environmental impact, emitted noise and cost of the aircraft, while providing a slightly better performance.

The main areas of improvements are stall characteristics, roll and stall control, as well as lift to drag ratio. Morphic wing arrangements can have a positive impact on

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endurance and range characteristics. A wing of any shape can be optimized for a wide range of lift coefficient to generate the same amount of induced drag as an elliptic wing. Variable wing camber paired together with seamless skin is a promising solution for high noise generation during specific mission profile segments. It was also shown that such arrangements may improve aeroelastic efficiency and increase the critical flutter velocity [3].

Machines engineered by humans tend to be rigid, connected by different joins or interfaces, whereas morphing arrangements take inspiration from nature, where structures are able to adapt their shape in a very large range to maximize their performance and are often flexible or compliant, whilst still offering required strength [4].

The utilization of concepts found in nature that use flexibility in morphing designs is based on embracing elasticity, instead of avoiding it. Just like the mechanisms that are the base for this approach, it is essential to create a system that is both flexible and strong, able to withstand the dynamic forces and additionally simple, when number of parts are taken into account [6].

To achieve those contradictory quantities, mechanism sections need to simultaneously carry the loads as well as perform all kinematic functions. This approach leads to reduced mechanical complexity and number of elements.

Methods in which morphing wings are implemented are based on changing the shape of the wing during its operation, to maximize the performance or achieve other goals, such as noise reduction and include variation of chord length, swept angle, wingspan and angle of attack, as well as bending spanwise or chordwise. Morphing by varying the angle of attack is called twist morphing [6, 8, 11].

Wing can be morphed in different ways, the simplest one was developed as a direct replacement for conventional mechanisms, promising improvements in parasitic drag by incorporating seamless skin, to reduce the parasitic drag on aerodynamic surfaces [9].

Table 1. Morphing solutions classification.

Solution	**Trailing Edge**	**Camber**	**Wing**
Shape Memory Alloy	SMA Actuation	SMA Actuated Skin	
Piezoelectric	Piezoelectric Actuation	Piezoelectric Actuated Skin	
Nature Inspired		Muscle Function & Plant-Movement	Hyper-Elliptic Cambered Span [4]
Torsional			Twist Morphing [11]
Passive		Hexachiral Prismatic Wingbox	
Adaptive Compliant	Adaptive Compliant Trailing Edge Mission Adaptive Compliant Wing	Integrated Compliant Ribs	
Modified Classical Mechanisms	Seamless Skin Flap		

One simple method for changing the camber is the finger-like concept, where the rib is divided into segments connected by hinges in order to allow for the desired motion.

Approaches based on rigid motion can also be found, such as piezoelectric actuators to excite a tab that moves a free-floating trailing edge flap, or SMA wire to rotate a tab for thickening the trailing edge [7].

Active skin made of an array of piezoceramic actuators can be used to achieve a deformation of the trailing edge [7].

Chiral honeycomb could be used as the internal structure of the aft section of a passive morphing (decambering) airfoil [5].

Compliant trailing edge section can be made, which is actuated with a SMA wire. The trailing edge is free to slide into the spar, thus allowing for large displacements. Similarly, the Mission Adaptive Compliant Wing (MACW) from FlexSys Inc. uses a compliant mechanism for morphing the trailing edge [2, 3].

Morphing trailing edge actuated by dielectric elastomers integrated in the skin was suggested. The rear part of the profile acts as a servo tab, thus reducing the required actuation forces [7].

Typical approach to morphing wing design is interdisciplinary, as shown on Figure 3. The challenge of achieving a transdisciplinary information exchange lies in the broad range of needed methods lying within those disciplines to manage [10].

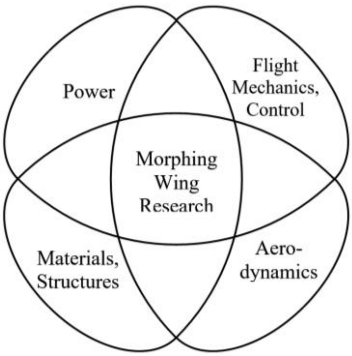

Figure 1. Typical Interdisciplinary approach.

1. HALE aircraft

High-Altitude Long Endurance (HALE) is the description of an air-borne vehicle which functions optimally at high-altitude (as high as 20 km) and is capable of flights which last for considerable periods of time without recourse to landing.

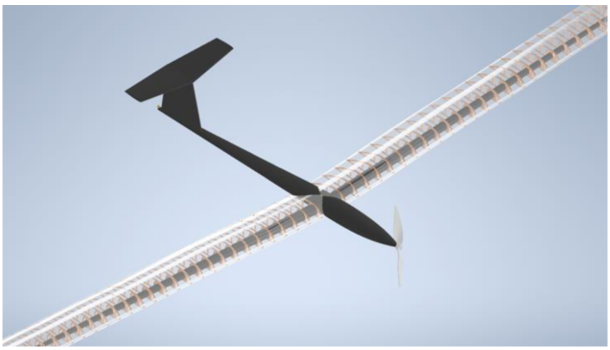

Figure 2. HALE aircraft.

Oracover foil as skin is widely used in HALE aircrafts as its leightweight. Plywood ribs can also be used. There is no need for using lift devices, as the take-off is performed from hand or using a small catapult device. Ailerons, elevator and rudder are used. Ribs usually have changing geometry along the wing. To reduce rib weight in the furthest ribs from the root, some additional cut outs can be put into place. An example of HALE aircraft is shown in Figures 2 – 3.

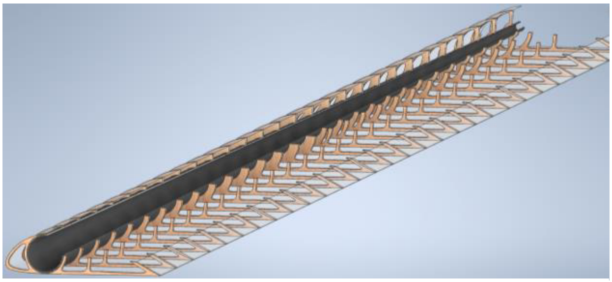

Figure 3. Wing structure, three-quarter section.

2. Morphing wing concept

The challenge morphing wing transdisciplinary design aims to solve is effective and efficient design development of said wing arrangements. Increased availability and introduction rate of efficient morphing wing designs for production are main expected impacts such methodology aims to achieve.

As the solution spans inventive methodology, aerodynamics, structures and materials, flight mechanics and control, the development process must be structured and as such comprises of four phases: inventive methodology approach utilisation to determine the design arrangement, flight mechanics and control considerations, structural and material considerations and aerodynamic verification. In the development process there should be an aircraft designer and preferably aerodynamics specialist, as well as mechanical engineer involved. The validation is up to the aircraft designer and should be comprised of aerodynamic analysis verification as well as direct comparison of arrangements.

To identify the best viable solution for the HALE aircraft, TRIZ methodology was utilized. TRIZ (Theory of the Resolution of Invention-Related Tasks) is a problem-solving, analysis and forecasting tool derived from the study of patterns of invention in the global patent literature the theory of inventive problem solving and occasionally goes by the English acronym TIPS.

This theory defines generalizable patterns in the nature of inventive solutions and the distinguishing characteristics of the problems that these inventions have overcome. An important part of the theory is revealing patterns of evolution and one of the objectives of TRIZ has been the development of an algorithmic approach to the invention of new systems, and to the refinement of existing ones. [12]

It is important to determine which features of the design ought to be improved. The idea of morphic wing is to improve adaptability, that's why it was chosen for the analysis as the main improved feature. Based on TRIZ decision matrix, the following principles would be used to determine the new design:

1. The principle of division:
   - 1.1. Divide an object into independent parts
   - 1.2. Make a disassembling object
   - 1.3. Increase segmentation
2. The principle of versatility:
   - 2.1. Make an object capable of carrying out several steps to replace the activities carried out by other parts of the object

3. The principle of counterweight:
   3.1. Balance the weight of an object by connecting to one or more other objects with lifting force
   3.2. Balance the weight of the object by ensuring interaction with the environment (using aerodynamic forces)
4. The principle of dynamism:
   4.1. Allow matching the characteristics of the object so as to make the operation optimal, or to move under the best operating conditions
   4.2. Divide an object into elements that can move together
   4.3. Make a flexible or adaptable object (or process) which was previously rigid and not flexible
5. The principle of local quality:
   5.1. Go from the structure of a homogeneous object to a heterogeneous structure
   5.2. Make each part of the object perform different activities in the best possible conditions
   5.3. Specialize different parts of the object (make each part perform a different useful activity)
6. The principle of isolation:
   6.1. Use flexible shells and thin films instead of three-dimensional structures
   6.2. Isolate the object from the external environment using flexible shells and thin films
7. Inversion principle:
   7.1. Reverse the useful action normally used to solve the problem
   7.2. Immobilize mutually movable parts but set in motion parts that were still [1, 12-14].

The design that allows to achieve all of the above principles, which is an adaptive compliant structure proposed to meet these requirements, as well as its functioning model is shown in Figures 4 – 5.

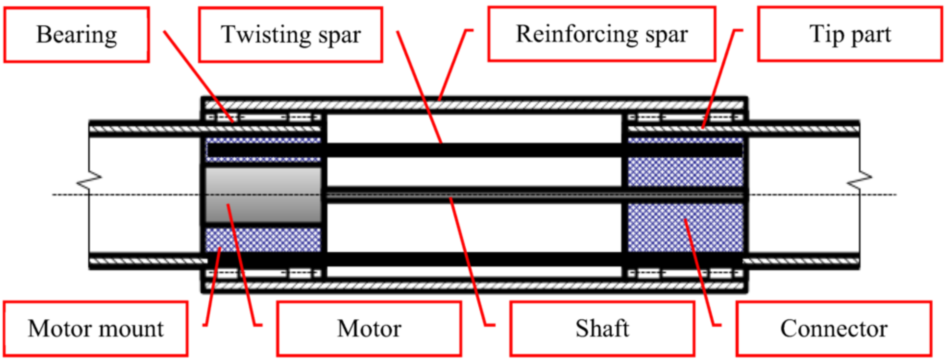

Figure 4. Wingtip Twist Morphing concept.

This design focuses on changing of the angle of attack of part of the wing at its tip. Spar is divided into 3 (unreinforced spar) or 4 (reinforced spar) elements. The tip-most part is allowed to twist by incorporating a split tubular spar, incorporated in and supported by an outside tubular spar (in reinforced spar version), that is put into place solely to carry the bending loads.

Twist of the wing is controlled by servomotor fixed to the spar. Torque generated by the servomotor is carried through an elastic clutch by a CFRP shaft to the second fixing point.

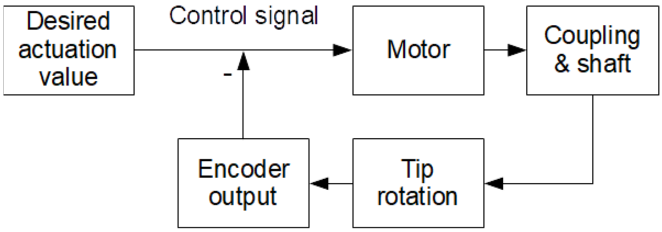

Figure 5. Wingtip Twist Morphing working principle.

3. Analysis

The analysis was performed on HALE aircraft under development in SkyTech eLab „Twin Stratos".

During the analysis the main problem that should be solved is the aerodynamic performance of considered design. The airplane structure was reconstructed in XFLR5 software as shown in Figure 6.

The aircraft main wing is divided into several sections with differing chord and dihedrals. Different versions of roll control elements are taken into account. The following analysis compares 3 options of control – clasical with ailreons, tail control, wingtip twist morphing.

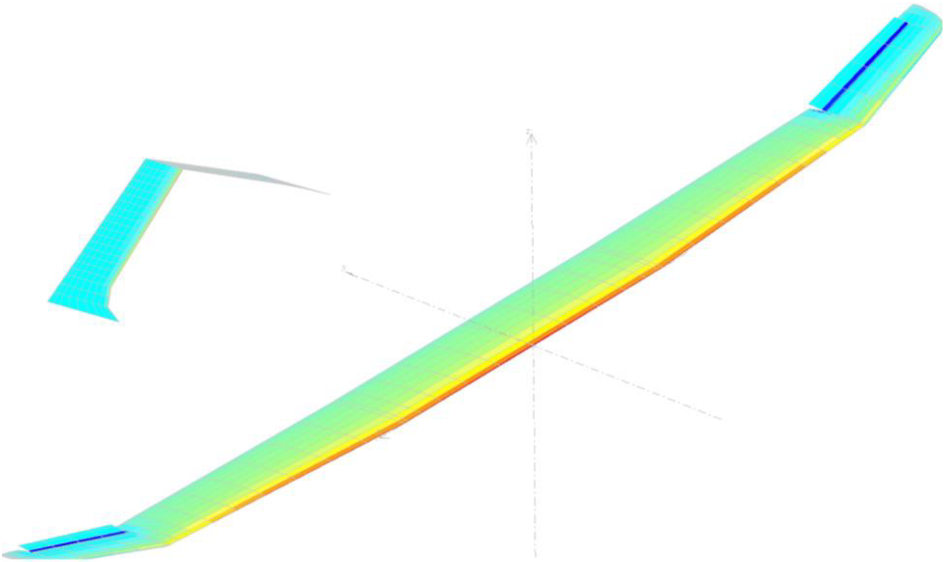

Figure 6. Considered aircraft reconstructed in XFLR5 software.

Data regarding lift coefficient was gathered and processed for the purpose of calculations and rendered results shown in Figures below. Figures 7 – 9 show lift coefficient distributions in all considered arrangements, for 0°, 5,5° and 10° angle of attack.

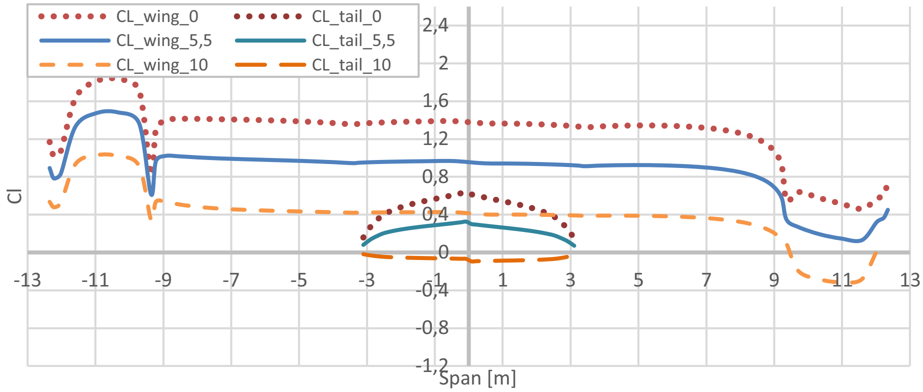

Figure 7. Lift coefficient distribution (ailerons).

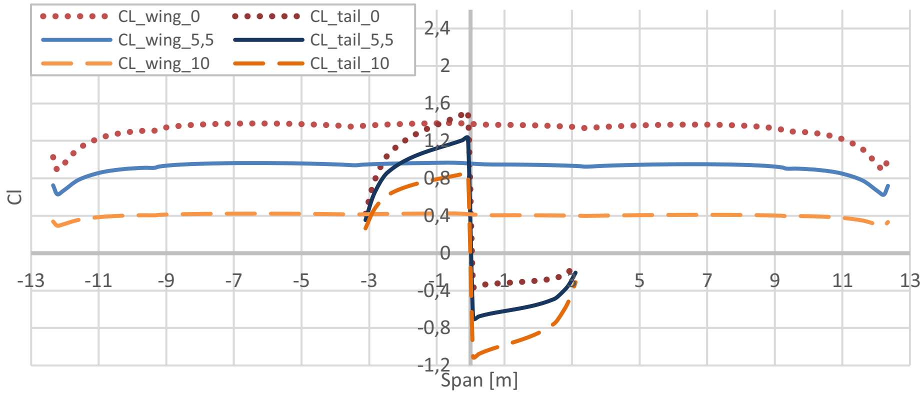

Figure 8. Lift coefficient distribution (tail compliant trailing edge).

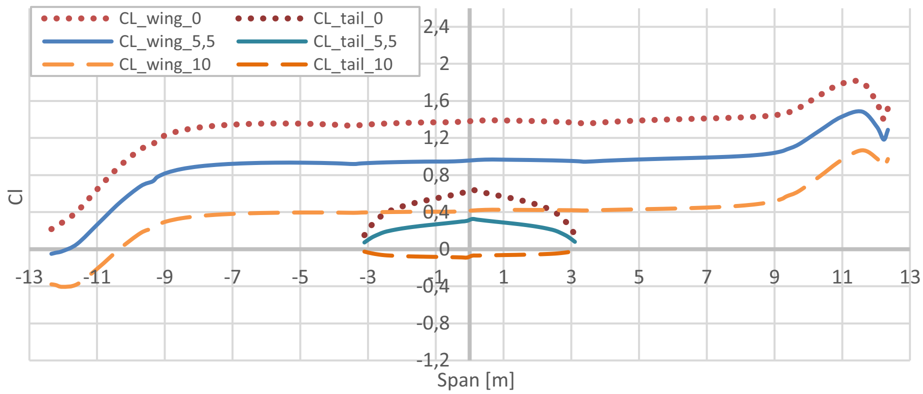

Figure 9. Lift coefficient distribution (wingtip twist morphing).

To conclude the analysis, the data was gathered to calculate both lift and rolling moment for all considered arrangements. The total lift and rolling moment, as well as their respective improvements in comparison to the classical control system are shown in Tables 2 – 3.

Lift increased significantly in the tail control arrangement and reached about 5,57% increase for 0° angle of attack. Results for Twist Morphing show, that the improvement is much less dependent on AoA.

Table 2. Lift and its improvement in comparison to classical control system.

AoA [deg]	Aileron control	Tail control	Twist Morphing (wing tip)	
0	672	710	707	L [N]
	0.00	5.57	5.14	Impr. [%]
5.5	1662	1751	1743	L [N]
	0.00	5.38	4.88	Impr.[%]
10	2437	2567	2554	L [N]
	0.00	5.34	4.82	Impr. [%]

Rolling moment increased in both arrangements and reached about 9% increase for 0° angle of attack in the tail control arrangement. Twist Morphing yielded an increase of over 6%.

Table 3. Rolling moment and its improvement in comparison to classical control system.

AoA [deg]	Aileron control	Tail control	Twist Morphing (wing tip)	
0	4670	5091	4984	M [Nm]
	0.00	9.00	6.72	Impr. [%]
5.5	10725	11662	11473	M [Nm]
	0.00	8.74	6.97	Impr. [%]
10	15458	16799	16545	M [Nm]
	0.00	8.68	7.03	Impr. [%]

Figures 10 – 13 shown below give a representation of results of lift and rolling moment. Improvements are presented in Figures 12 – 13.

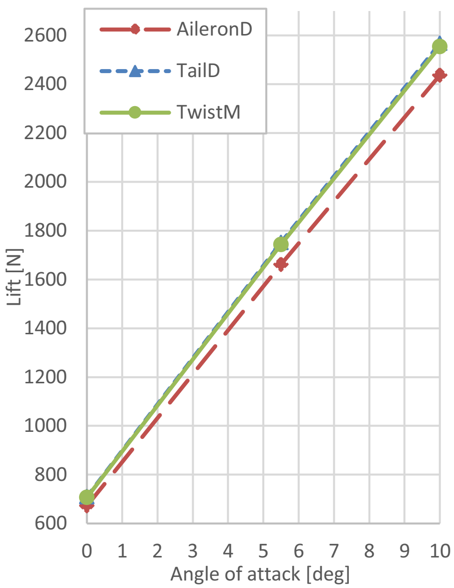

Figure 10. Lift vs angle of attack.

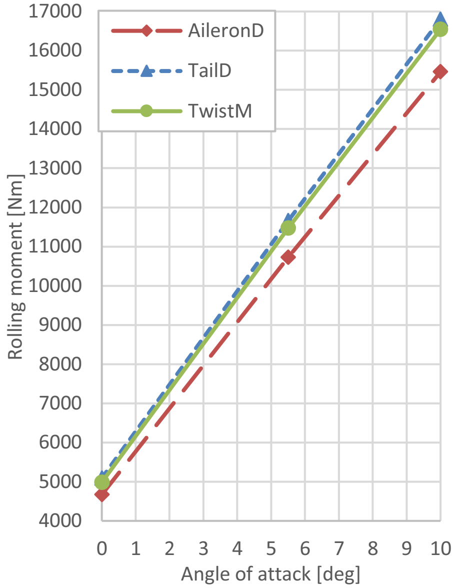

Figure 11. Rolling moment vs angle of attack.

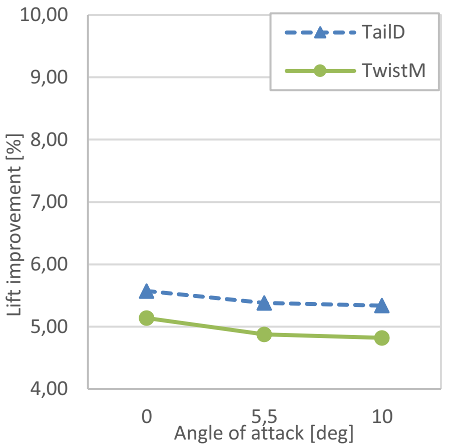

Figure 12. Lift improvement vs AoA.

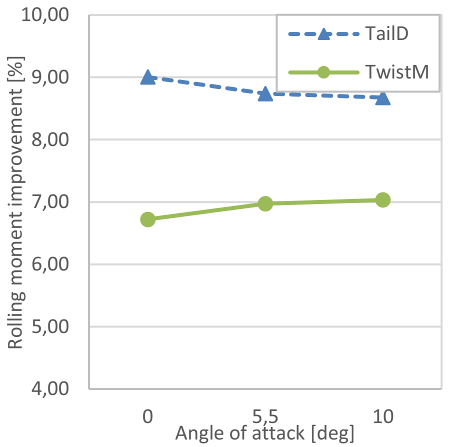

Figure 13. Rolling moment improvement vs AoA.

4. Conclusions

The considered arrangements of control surfaces were able to improve the rolling moment in all considered angle of attack scenarios by several percent. Additionally, lift also increased in comparison to classical control system, which in addition to reduced parasitic drag concludes, that such arrangements can be desirable for utilisation in High Altitude Long Endurance UAVs. For the considered aircraft and angle of attack ranges, the tail control arrangement offers the best improvements of up to 9%.

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We wanted to express gratitude for SkyTech eLab company for providing technical documentation of the Twin Stratos UAV project for research purposes.

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Vulnerability Analysis of Road Networks Based on Hierarchical Models

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Abstract. Road users are always expecting safe, fast, comfortable and predictable journeys both on a daily basis and on special occasions. Damage events that are predictable to a road network are challenges but those with difficulties to foresee are even greater. Vulnerability is critical in dealing with particularly high impact low chance events. In this paper the vulnerability of a road network is quantified to identify the weaknesses in the form of a road network. Theories of topology, structural vulnerability and road traffic are utilized in this paper. Based on the authors' previous work with modifications for basic concepts and variables, analysis is improved in this paper to include measures for the assessment of the form of both links and vertices. Transmittance of actual traffic flow is firstly considered for the function evaluation of a network. Traffic rerouting and reassignment is incorporated in the identification process of candidate vulnerable failure scenarios. It is proved in this paper that road networks do have weak points, single or combined, where if congested may cause great loss of function to local areas or the entire network. Findings in this paper are strong supportive points of research for the propagation of more delicate-designed and form-improved road networks in urban areas. Adaption of the current work can be made when various practical cases are involved. The vulnerability of traffic networks serving various traffic modes in a city is to be considered as future work.

Keywords. Vulnerability; road network; form; function; traffic reassignment; failure scenario.

Introduction

Threats with lower frequency occurrence that can cause parts of road networks incompetence include severe weather, natural disasters or targeted attacks. High profile events have brought enormous attention to the research on disruption to transport networks such as the airline network disrupted by the 2010 volcanic ash cloud in Iceland [1], road and railway networks submerged by the floods in Columbia in 2011[2]and Canada in 2013[3].

In[4]vulnerability is defined as the susceptibility to rare and fatal risks, whereby victims can hardly change the course of events and contribute little to recovery. The features and consequences of damage events were both addressed. In[5]it was discussed that the results of incidents should be emphasized rather than their physical nature.In many vulnerability analysis of a road network, results (consequences) of damage events

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have been evaluated by the change of 1) topological and inner characteristics of network elements and/or 2) user-oriented performances presented by the impaired network.

Topological features of a complex road networks such as vertex degree, edge betweenness and network diameter are considered to represent the excellence of the form of the networks[6-7]. Many of these measures do not reflect how well the actual flow is transmitted by the network elements whether the network is damaged or not.

The performance of a road network is usually measured by the cost paid to reach destinations by the moving flow in the network. Travel time is one of the most commonly used variables to assess the movement of traffic flow[8-9]. When another measure of the network performance, link capacity is subject to random variations due to user routing choices, it is possible for the network capacity to fluctuate around a required demand level[10]. Accessibility of a location or zone in a road network is a good measure of road network performance integrating zone attractiveness as inner features of a network such as population, number of stores and also the cost of traffic flow such as travel time, traffic volume [11-12]. In [13] the capacity bottlenecks in transport networkds are identified by capacity weighted spectral partioning analysis.

For this paper the concept of vulnerability proposed by[14]: "A road network is vulnerable if damage to a small part of the network results in the failure of a significant part or whole of it." The concept is concerned with the disproportionateness of the consequences in relation to the damage[15]and it was firstly applied to structural systems [16]. In the analysis it is the effort to cause damage events to be considered rather than probability of occurrence, predictability and nature of damage events. Consequences of damage events are measured by the change of the form and function of a road network. The form of a road network depends on its connectivity and characteristics of the network elements. The function of a road network is defined here as the service provided by network elements to vehicle traffic and local population.

1. Topology and function of road networks

The analysis draws upon concepts from graph theory, road traffic theory and structural vulnerability theory[17].

1.1. Graphs of road networks

A road network can be represented by a set of edges (i.e. a link of two directions or an arc of one direction) connected at vertices in a graph model. Defined in [21], a road network is formed by a set of road circuits. A road circuit is a closed road route that provides two non-overlapped paths between a pair of vertices. The origin and destination of a circuit are the same (i.e. traffic leaves and returns to the same origin) but without visiting any other node more than once. The environmental area, framed by a basic road circuit, is usually the urban residential area, the business district or the covering area of a city or the stacking area in a container terminal yard. A basic road circuit and its environmental area is the smallest functional unit of an operating road network.

1.2. Forms of road networks

As both are physical systems, a direct analogy has been used between a structure and a road network in order to examine the relationship between cause and effect[21]. The two systems are both dynamically functional ones due to connectivity among their elements.

It is the form of either system that determines the systematic response by a changing flow to a changing potential.

Well-formedness is a common definition that describes the quality of the form of a network system. It can have various specific meanings with regard to different network systems. A well formed structure can withstand loading from any arbitrary direction. A well formed road network can provide stable and flexible services to its users such that trips can be made in any arbitrary direction i.e. from any vertex to any other within expected or accepted time. A new concept of continuance is a basis for the development of a measure of the well-formedness of a road network.

Continuance was developed through traffic modulus (K) from an analogy with Young's modulus in structural mechanics[21]. Defined as traffic flow over traffic strain, traffic modulus describes the relationship between actual traffic flow and actual travel time in the system dynamic terms. Combined with the fundamental relationship between flow and travel time defined in traffic flow theory, the continuance of a road lane is defined as in Equation 1.

$$tr_l = \frac{Q}{(t_c - t_f)L} \tag{1}$$

where Q is capacity flow, the maximum sustainable flow rate at which vehicle or people reasonably can be expected to traverse a point or uniform segment of a lane or roadway during a specified time period under given conditions; t_c is capacity travel time along the lane; t_f is the travel time for free uninterrupted flow; L is the lane length.

Continuance is always positive and directly proportional to the capacity flow of a road lane. For a road section with multiple lanes, continuance can be taken as the simple summation of each lane-though in practice there will be interference between the lanes.

2. Form of road network elements

2.1. Well-formedness of a road location and a road circuit

Vertex well-formedness depends upon the continuance, orientations of intersecting links and functional characteristics of this vertex. Functional characteristics of a vertex may include 1) its type if it is a junction (e.g. roundabout, signal-controlled etc.); 2) its size if it is a location (e.g. population, number of stores, number of activities etc.); 3) its social utility (e.g. a hospital, a school, a police station etc.). Since a global coordinate system for a road network in real world can be the north-south geographical coordinate system, the orientation of a link is reflected in a 2×2 matrix indicating the relative directionality of this link with respect to a defined co-ordinated system for the whole network. A link continuance matrix is the product of the continuance and orientation matrix of this link. The measure of vertex continuance is the determinant of the summation matrix of the continuance matrices of all the links as in Eq. 2.

$$\begin{aligned}[M_{li}] &= \frac{Q}{(t_c - t_f)\cdot L} \cdot \left[\begin{array}{cc:cc} \cos^2\theta & \sin\theta\cos\theta & 0 & 0 \\ \sin\theta\cos\theta & \sin^2\theta & 0 & 0 \\ \hdashline 0 & 0 & \cos^2\theta & \sin\theta\cos\theta \\ 0 & 0 & \sin\theta\cos\theta & \sin^2\theta \end{array}\right] \\ &= \begin{bmatrix} [M]_{11} & [M]_{12} \\ [M]_{21} & [M]_{22} \end{bmatrix} \end{aligned} \tag{2}$$

where θ is the orietation of link li.

The vertex transmittance matrix for a vertex is the summation of the link transmittance matrices for the links starting from this vertex. For a vertex with several joining links, the matrix is defined as:

$$[M_v]^i = \begin{bmatrix} \sum_j [M_{li}]^j & 0 \\ 0 & 0 \end{bmatrix} \quad j = 1,2,\cdots t. \tag{3}$$

where $[M_a]^j$is the link transmittance matrix in Eq. 2for link *j*, *t* is the number of links from vertex i.

Besides vertex continuance measuring the vertex form, weights are given here to vertices to represent their relative functional importance. By referring to the functional importance of a vertex in a road network, the vertex is now considered as a zone or an area but not assumed as a relatively tiny joint point of links where it takes no time for traffic flow to pass through as in the evaluation of vertex continuance. Travel time through vertices of a roundabout or a signal-controlled junction may be different. And travel time through junctions affects flow continuance along road sections and flow continuance around a road circuit.

A reference node is defined here as a population centre such as a town or a district within a town of interest, chosen by the analyst as being of direct interest and which if disconnected from the network would cause a major loss of functionality. It is sufficient but not necessary for vertices with relatively large weights of function to be chosen as reference nodes. Similar to the ground as the reference in structural vulnerability analysis, separation from reference nodes in a road network is defined as the failure of a road network. A reference circuit is one of the independent road circuits including one or more than one reference nodes.

For the network of a city in Figure 1(a), assume that Vertex x_1 is the city centre and Vertex x_{10} is a hospital and the rest vertices are residential areas with various scales of populations. Vertex x_1 and Vertex x_{10} are chosen as reference nodes in the network. The function values are in boxes.

The well-formedness of a road circuit is defined as the sum of weighted vertex continuance divided by the number of vertices as in Equation 4.

$$Wf_{cir} = \frac{\sum_i f_v{}^i \cdot tr_v^i}{N_v} \quad i = (1,2,\cdots,N_v) \tag{4}$$

where $f_v{}^i$ is the weight of vertex i, N_v is the total number of vertices in the circuit Cir.

In summary this proposed well-formedness measure is based on the form, number of connections and function of a vertex indicating the ease of continuation of flow through vertices with varied importance.

The damage demand for a road network is the effort required to cause the loss, by a road circuit, of its capacity to transmit traffic along a road section contained in the circuit. It is defined as being directly proportional to the traffic modulus of a road section.

2.2. Road clusters and clustering process

Some neighbouring circuits are clustered into a better-formed sub-network thus a road network can have a few sub-networks with different well-formedness and the relationship between them can be discovered during clustering.

The clustering process for a road network begins by identifying all of the basic road circuits and calculating their well-formedness. Clusters are grown by including the neighbouring circuits so as to result in the most increase (or least decrease) in the well-formedness. When two clusters have the same well-formedness, the other four measures are maximised during the selection of candidate circuits in the order of priority.

A hierarchy model of a road network presents the clustering process starting from bottom to top. The higher the level the smaller is the number of clusters and the smaller amount of detailed information.

Take the network (see Figure 1(a)) with 10 vertices and 19 links for example. Vertices x_1 and x_{10} are reference nodes. The functions of vertices from x_1 to x_{10} are presented in boxes in Figure 1 (b). There are 10 basic circuits which are shown in Figure 2 with their well-formedness. Circuit 1, 3, 6 and 8 are reference circuits. The properties of some links are given in Table 1.

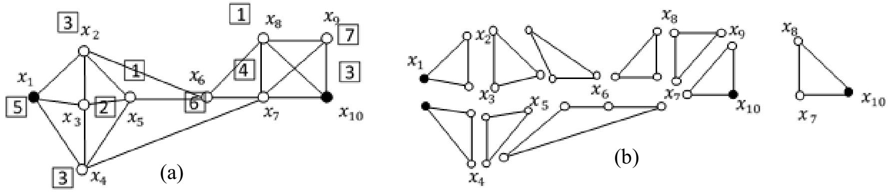

Figure 1. Basic road circuits of the road network.

Table 1. Properties of some links in the road network in Figure 1.

Link Vertices		$\frac{Q}{(t_c - t_f)}$	L	θ	Continuance/Damage demand
Location 1	Location 2	$\frac{\text{Number of vehicles} \cdot \text{km}}{\text{t}^2 \cdot \text{Lane}}$	km	radian	$\frac{\text{Number of vehicles}}{\text{t}^2 \cdot \text{Lane}}$
x_1	x_2	69.04	1	0.52	69.04
x_1	x_3	69.04	1	2.62	69.04
x_1	x_4	69.04	1.73	2.09	39.86
x_9	x_{10}	69.04	0.73	1.57	94.30

The clustering process and corresponding hierarchy are illustrated in Figure 2. Two reference clusters (Cluster 16 and Cluster 17) are connected by a non-reference cluster (Cluster 15). Cluster 16 has the largest well-formedness among Cluster 15, 16 and 17. Four of the five links in the cluster, i.e. link x7- x8, x7- x10, x8- x10, x7- x9 and x9-x10 have the largest continuance (94.30) among all the links. Circuit x7-x8-x10 and x7-x9-x10 have high well-formedness and they are tightly connected with a high algebraic connectivity (small number of vertices and large number of links). Vertex x7 in this cluster has the highest function of 7. The other reference cluster, Cluster 17 has the lowest well-formedness among the three clusters. Five links in this cluster have lower continuance and function than those of the links in Cluster 16. The non-reference cluster, Cluster 15 has eight vertices and thirteen links that are interconnected. Redundant routes of large continuance are provided between any pair of vertices in this cluster.

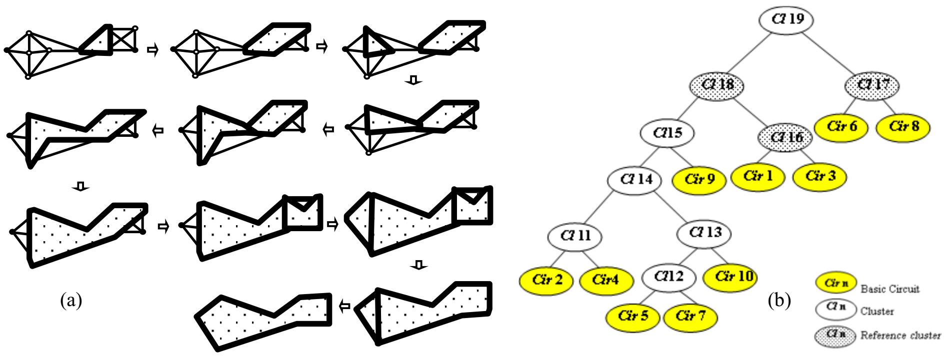

Figure 2. The clustering process (a) and the hierarchical representation(b) of the network in Figure 1.

3. Unzipping of road networks

3.1. Failure scenarios of road networks

A failure scenario includes a series of damage events in which some vertices are disconnected from others in the circuit. Locations of damage events may result in consequences which vary from little i.e. reference nodes are still connected to each other and the well-formedness of the paths between them is not greatly damaged to extreme i.e. all of the nodes are separated from each other.

Two of the essential aspects of consequences are separateness and loss of function. Separateness is a change in the form of a road network whilst loss of function is a change in the accessibility between pairs of reference nodes. Separateness (S) is defined as a ratio of the loss in cluster well-formedness to the well-formedness of the intact network[21]. Damage to connectivity among reference nodes is reflected by loss of Function (F) as defined in Equation 5.

$$F = \frac{\sum_i f_v{}^i \cdot f_v^j - \sum_m f_v{}^m \cdot f_v^n}{\sum_i f_v{}^i \cdot f_v^j} \tag{5}$$

where $f_v{}^i$ and $f_v{}^j$ is the function of any pair of connected nodes i and j in the original network; $f_v{}^m$ and $f_v{}^n$ is the function of any pair of nodes m and n in the damage network. When $\boldsymbol{F}$=**1**, all function of the network is lost; when $\boldsymbol{F}$=**0**, the network is intact; the higher value of $\boldsymbol{F}$, the more likely for reference nodes is to be disconnected.

Neither separateness nor loss of function can fully represent the meaning of consequences to damage events. Function loss can be great when reference nodes with large function values are separated from other vertices. Therefore consequence (Co) is defined as equal to the maximum value of S and F.

Damage demand of a damage event to a link is equal to the sum of the continuance of component lanes. For more than one damage event to corresponding links it is the sum of damage demand of each link. To compare the vulnerability between different networks, the measure of relative damage demand is used.

Vulnerability index (VI) of a failure scenario is the ratio of the consequences to the relative damage demand of that scenario. This index changes with different identified scenario rather than an internal feature with a constant value. It is non-dimensional so comparisons can be made between failure scenarios in a road network and between failure scenarios in different networks.

The unzipping process searching for failure scenarios starts from the top of the hierarchy and ends in the bottom. Each cluster at each level in the hierarchy is damaged by the separation of its sub-clusters. Each separation consists of a set of links that are identified one by one referring to the unzipping criteria defined in[21]. Those links form a candidate failure scenario.

In order to identify further damage events that will lead to more partial failure scenarios, the damaged network is re-clustered and a corresponding hierarchical model is generated after a clustering process. The next event is identified using the same unzipping process but using the newly generated hierarchy. The process of re-clustering and unzipping after each event is repeated until total separation occurs or all functionality is lost. Theoretically re-clustering and unzipping can be performed many times to identify all of the candidate scenarios for a network but we assume that two sets of analyses are sufficient. The first set of candidate scenarios are identified through the unzipping process without re-clustering and the second set of scenarios is generated after the first link in each scenario in the first set is removed and the network is re-clustered.

Figure 3 shows the network and its hierarchical model. Vertices 1 and 16 are reference nodes. Damage demand of each link in the network is identical as 69.04 and each link contains two lanes of opposite directions. The function value for each reference node (Vertex 1 and Vertex 10) is 10 and for the rest vertices the function values are identical as 1. Well-formedness for Circuit 1 to Circuits 9 is shown in Figure 3 (a).

Different from the authors' previous work, traffic flow distribution is firstly performed here in the unzipping process together with re-clustering. At the first step traffic flow is assigned between a pair of reference nodes as origin and destination (OD) and distributed over the network. The first damage event is identified in the aforementioned process. After every damage event the traffic flow is re-distributed. If the new traffic flow on a link exceeds the link capacity, this link is considered to be damaged as the next damage event and the network is re-clustered. If no such link appears, the second damage event is identified during the re-clustering and unzipping process.

Assume that 100 vehicles per hour are flowing from the origin, Vertex 1 to the destination, Vertex 10. The flow in this network is assigned in equilibriu m as presented in Figure 3(b). Assume that the capacity of each link is 80 veh/hour.

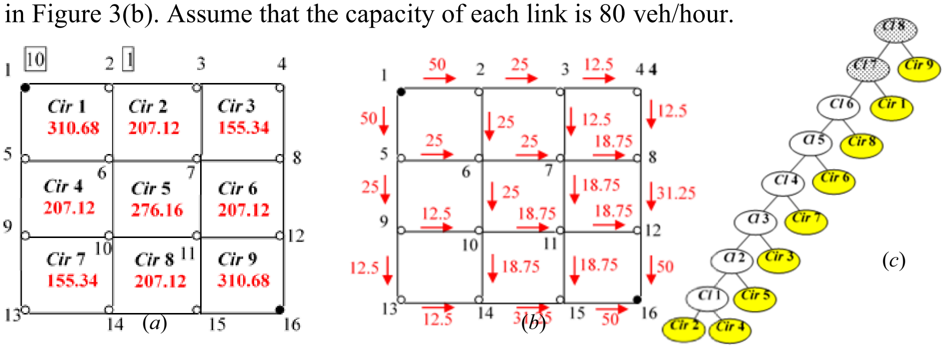

Figure 3. The grid network(*a*), traffic flow distribution (*b*) and the hierarchical model(*c*).

Some candidate failure scenarios are identified in the unzipping process with and without re-clustering and are listed in Table 4.

The maximum failure scenario is Scenario a-15, i.e. the damage to link 1–2 in Table 4. The scenario is neither a total failure nor a partial failure. Since the network is symmetric horizontally, vertically and diagonally, it is apparent that there are four maximum failure scenarios, besides link 1–2, damage to link 1–5, link 12–16 and link 15–16 are the other three maximum failure scenarios respectively. Common features of the four failure scenarios are firstly, they have the smallest damage demand therefore these four failure scenarios are also minimum damage demand scenarios. Secondly the connectivity between two reference nodes and one reference node with other vertices is half damaged, i.e. one reference node is half separated from other vertices since one of the two paths connecting a reference node to the rest of the network is damaged in the failure scenarios.

Scenarios containing one of the four links (link 1–2, 1–5, 12–16 and 15–16) have large consequences, for example Scenario a-1, a-2, b-1, b-2, b-3, b-124. However relative damage demand is different for these scenarios. It can be concluded that links directly connecting reference nodes especially those with relatively high function values play critical roles in network vulnerability. Damage to links connecting reference nodes would either lead to great separation or large function loss of the whole network.

Table 4. Vulnerability results for the network in Figure 3.

No.	Candidate failure scenario	Relative damage demand	Consequence	Vulnerability index
(a) without re-clustering				
a-1	12–16, 15–16	0.08	0.44	5.5
a-2	1–2, 1–5	0.08	0.44	5.5
a-3	5–6	0.04	0.07	1.75
a-14	8–12, 11–12	0.08	0.09	1.13
a-15	1–2	0.04	0.43	10.75
a-16	2–3	0.04	0.04	1
a-17	3–4	0.04	0.04	1
(b) *with re-clustering after damage to first link (greyed out)*				
b-1	**11–15**,12–16,14–15	0.13	0.46	3.68
b-2	**11–15**, 1–2, 1–5	0.13	0.44	3.52
b-3	**8–12**, 11–12, 15–16	0.13	0.44	3.52
……				
b-124	**3–4**, 1–2	0.08	0.46	5.54
b-125	**3–4**, 9–13, 13–14	0.13	0.09	0.72
b-126	**2–3**, 9–13, 13–14	0.13	0.09	0.72

3.2. *The inclusion of traffic flow distribution*

During unzipping and re-clustering processes re-distribution of traffic flow is performed after each damage event is identified. Assume link 5–6 in Scenario a-3 in Table 4 is chosen as the first damage event. Figure 4 shows the unzipping process with the change of traffic flow on each link after the damage.

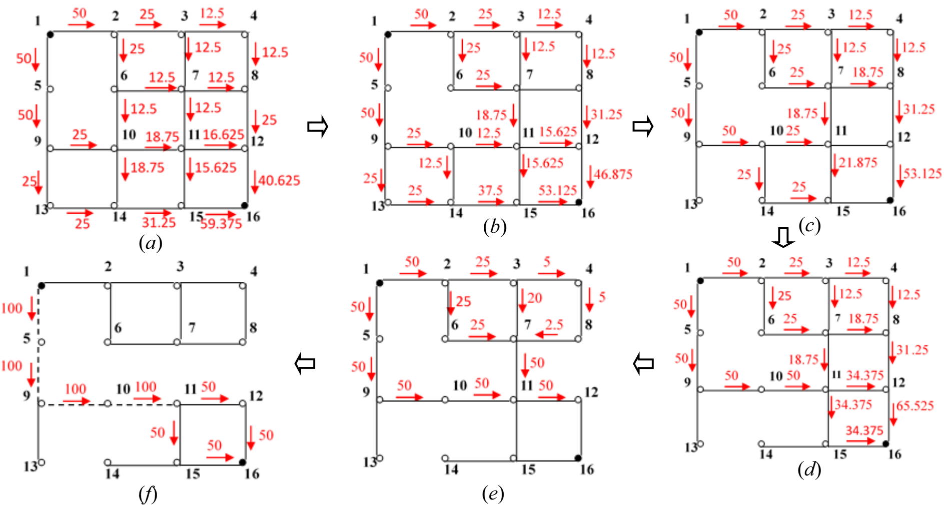

Figure 4. The unzipping process with the change of traffic flow.

From Figure 4 (a) to (e), traffic flow on links is changing and returning to a new equilibrium after each damage event. Since the link capacity is 80 veh/hour, no link is identified when the traffic flow exceeds its capacity in these steps in Figure 4. The damaged links are identified in the unzipping process when re-clustering is performed after each event. In Figure 4 (f), the only one route between the reference nodes carries the whole traffic demand after link 7–11 is removed. Traffic flow on link 1–5, 5–9, 9–10 and 10–11 is 100 veh/hour, which exceeds the capacity (80 veh/hour) of any of the four links. The network is considered to be partially failed for the only route between the origin and destination is severely congested.

In summary by performing traffic flow re-distribution in the unzipping and re-clustering processes candidate failure scenarios are generated. The vulnerability indices of those scenarios may not be high since the number of links contained in the scenarios is larger than that of scenarios identified without considering the change of actual traffic flows. However it is more similar to everyday traffic conditions when the change of traffic flow is included in the vulnerability analysis.

4. Conclusions and future work

1. Systems thinking, graph theory, road traffic theory and structural vulnerability theory comprise the theoretical foundations of this research. The analysis may be adjusted and applied to other transport networks such as railway networks and other network systems in trandispline engineering fields such as water pipe network, electrical networks and the Internet.
2. The vulnerability analysis for a road network is a new method to evaluate the performance of the network experiencing damage events. The analysis focuses on the form of a road network with two aspects: topology and quality. It is the consequence and effort to cause damage events rather than the nature of those events that are measured in the analysis. The analysis is adapted from the structural vulnerability theory and is firstly applied in [21]. In this paper the analysis takes functions of a road network into account.
3. In a road network, road vertices, circuits and clusters are spots and they are connected by links. For links, their well-formedness is only measured by their continuance; for spots, their well-formedness is dependent on the continuance of their joining links and the functions they display. Functional importance of road spots reflects their social roles in a road network.
4. Clustering leads to hierarchical models of networks at various levels of granularity to facilitate more efficient searching for failure scenarios. Road vertices, circuits and clusters, all as road spots are at difference levels of hierarchy. A road network hierarchy helps to abstract various levels of information about the well-formedness of parts of the network.
5. A hierarchical model of a road network is unzipped in a search process for vulnerable failure scenarios that introduces a series of damage events according to pre-defined criteria. Scenarios containing links directly connected to reference nodes are often the ones with high consequences and if damage demand to these links is small, the scenarios would have high vulnerability indices. Links directly connecting to reference nodes should be paid special attention to when considering improving the form of a road network.
6. Failure scenarios with low vulnerability indices identified in the unzipping process may cause the change of traffic flow on other links. Traffic congestion on other links, in a short time can be seen as damage events thus additional links

should also be included in the failure scenarios. The rode network may be in partial failure under these failure scenarios.

7. The analysis results in scenarios that may help designers and engineers identify the most vulnerable parts of large road networks so that they can be redesigned, monitored or better maintained to increase robustness.
8. Results in this paper and those generated from other measures such as connectivity reliability, accessibility, vertex and link betweenness, small-worldness and limited path percolation(LPP) are supportive of each other. High vulnerable parts of a road network may have weak reliability and accessibility and weaknesses in terms of topology. Due to paper length limit, this part of research would not to be presented here.

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Knowledge and Data Modelling

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Customized Synthetic Dataset for Deep Learning Noise Filtering for Time-of-Flight Indoor Navigation Applications

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Abstract. Synthetic datasets have been used to train 2D and 3D image-based deep learning models, and they serve as also as performance benchmarking. Although some authors already use 3D models for the development of navigation systems, their applications do not consider noise sources, which affects 3D sensors. Time-of-Flight sensors are susceptible to noise and conventional filters have limitations depending on the scenario it will be applied. On the other hand, deep learning filters can be more invariant to changes and take into consideration contextual information to attenuate noise. However, to train a deep learning filter a noiseless ground truth is required, but highly accurate hardware would be need. Synthetic datasets are provided with ground truth data, and similar noise can be applied to it, creating a noisy dataset for a deep learning approach. This research explores the training of a noise removal application using deep learning trained only with the Flying Things synthetic dataset with ground truth data and applying random noise to it. The trained model is validated with the Middlebury dataset which contains real-world data. The research results show that training the deep learning architecture for noise removal with only a synthetic dataset is capable to achieve near state of art performance, and the proposed model is able to process 12bit resolution depth images instead of 8bit images. Future studies will evaluate the algorithm performance regarding real-time noise removal to allow embedded applications.

Keywords. Synthetic Dataset, Noise Removal, Time-of-Flight Image

Introduction

Human beings rely on their eyes to navigate through complex scenarios and avoid obstacles. When someone suffers from low-vision or blindness, their navigation ability gets compromised. Machines, on the other hand, uses a camera and other types of sensors to be able to perform autonomous navigation tasks. Differently from our eyes, sensors are not adaptable to complex lighting. Due to manufacturing limitations these sensors interpret some of these complex conditions as noise, causing autonomous navigation to work similarly to blindness or low-light vision.

Autonomous navigation applications require devices that are capable to extract data from the environment and transform them into a valid path. There are three main technologies that use computer vision to perform 3D reconstruction of the environment: stereo vision, Time-of-flight (ToF) camera, and LIDAR. ToF and LIDAR use logic similar to a sonar, but with a modulated near-infrared light. The stereo vision uses a pair of calibrated cameras and through epipolar constraints measure distance by matching the corresponding pixels from one image to the other. Stereo vision is usually cheaper, but is a more software-intensive task and requires great computational power to process the depth image, with the most accurate algorithms taking up to minutes to process a single pair of images and faster algorithms perform poorly on textureless regions. On the other hand, ToF cameras process everything in hardware, needing less computational power makes it a more attractive solution for embedded applications. Although LIDARs are more accurate and data processing is considerably fast, the acquisition cost is a huge limitation for several indoor applications or when a product requires production scalability.

One of the challenges of these technologies is to evaluate their depth measurement from each equipment and compare them with ground truth data. Ground truth with real data depth images is harder to obtain because ToF and Stereo normally contain a high noise level and LIDAR requires intensive scanning to generate dense accurate data, otherwise it will sparse. Since LIDAR has the most reliable performance, it is used to generate ground truth information, but due to LIDAR technical limitations, the dataset is usually sparse. Kitti dataset[1] is one example of a sparse ground-truth dataset.

Synthetic datasets become a very attractive solution to approach the lack of ground truth data, as the depth map generated is noiseless and dense, like on the Flying Things dataset [2] used for train/test stereo matching methods. Deep learning models are usually trained with real-world data or a combination of real-world and synthetic data. Since ToF real-world data is hard to obtain, this paper proposes an architecture that is trained only with the Flying Things synthetic dataset and the addition of synthetic Gaussian noise. The trained model is validated with the Middlebury dataset [3] which is a real-world source of the dataset.

1. Technological background

A ToF camera is an active sensor that uses the speed of light to calculate distance. The ToF camera mechanism measures the phase shift between the emitted modulated light and the received light which should be proportional to the distance between the emitter and the reflective object.

1.1. ToF noise and common filtering techniques

Like any other camera sensor, ToF camera is susceptible to undesirable effects like artifacts, unrealistic edges, blurred objects and disturbs background scenes caused by noise [4]. The source of noise can vary, as its statistical behavior, from the thermal vibration of the atom and discrete nature of radiation to the amplitude quantization process [5].

To attenuate the effect of noise, several traditional computer vision filters can be divided into two classes, spatial and temporal. Spatial filters use neighboring pixel values to filter noise. The most common are the mean, the median [6], and the bilateral filter [7]. However, temporal filters use the actual and past values of the same pixel to filter noise. The mean, the median, and the impulse response filter are the most common temporal filters.

Their effectiveness depends on the type of noise, but they all have disadvantages. Spatial filters are known to decrease image sharpness and temporal filters cause motion blur when objects are moving fast.

Combined computer vision algorithms to filter noise can achieve good results and still maintain some image structural integrity, but they are tailor-made for specific environments and they lack the ability to adapt to other scenarios. Recent deep learning architectures that use an encoder-decoder module are being applied to image reconstruction and image denoising tasks. These architectures can achieve great denoising performance while keeping image integrity [8].

1.2. Deep Learning

The base of all deep learning theory comes from the artificial neural networks which are made by a number of interconnected artificial neurons. The artificial neuron, as shown in Figure 1, perform a set of linear operations, equations, and then apply a non-linear behavior at the output signal using an activation function.

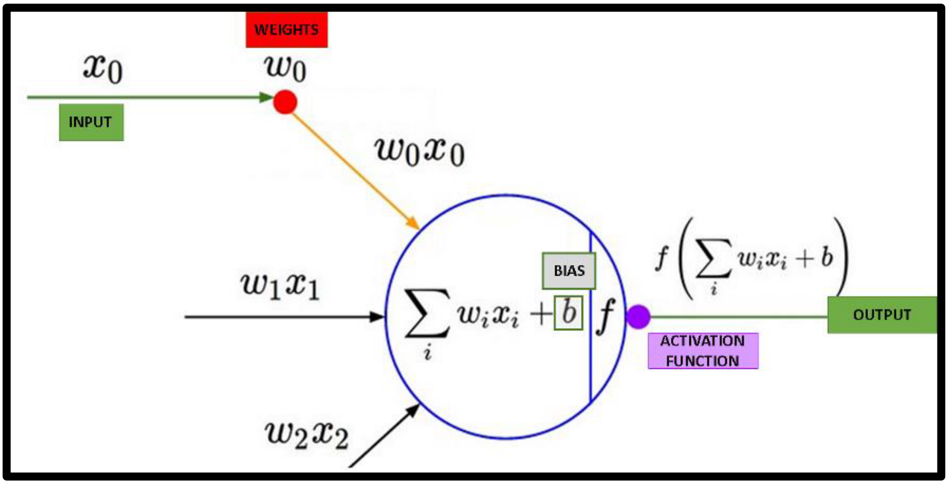

Figure 1. Example of an artificial neuron.

A simple artificial neural network is a supervised algorithm, which needs a dataset with known inputs and desired outputs. Any network must have an input and output layer and a variable number of hidden layers, which will depend on the selected architecture. Through backpropagation and optimizing technics, like gradient descent, to adjust the weights and minimize the error between the output and the desired value. The deep learning term refers to a neural network which has a great number of hidden layers, and Convolutional Neural Network (CNN) is one specific type of deep learning architecture.

CNNs refers to a neural network that uses convolution operations to extract features. The kernels used in the convolutions have the weights parameters embedded, in other words, the CNN learns which are the weight values for each kernel that extract features best.

A large number of architectures were developed for different types of applications: segmentation, object detection, stereo matching, image completion, image creation, image denoising, and many others. The encoder-decoder architecture is commonly used to image denoising. U-Net[9] is an example that uses the encoder to compresses the image into a latent space while reserving the primary components of objects in the image, thus eliminating noise. The decoder reconstructs the image from the latent space.

One of the very first encode-decoder networks used for image restoration was RED-Net [10] which showed that a deep learning model using downsampling and upsampling philosophy with convolutions, deconvolutions (transposed convolution) and skip connections can attenuate noise and still keep image detail. Some architectures also use shared parameters between convolutions and transposed convolutions of the same level [11, 12].

1.3. Synthetic Noise and Quality metric

Deep Learning models are most likely to be trained with real colored/greyscale images with noise added artificially, usually, Gaussian distributed noise with the mean value equals zero. The same principle can be applied to depth images, however, instead of 8bit per channel depth maps are normally higher. As deep learning is normally a supervised algorithm, the ground truth is needed, that is why the synthetic data for depth measurement is necessary as one of the most feasible ways to acquire noiseless images and also the reason why noise is added artificially.

To measure an algorithm's performance Peak Signal to Noise Ratio (PSNR) is a very common metric to validate the filter quality. PSNR (in dB) is defined as follows

$$\text{PSNR}=10*\log_{10}\left(\frac{\text{MAX}_\text{I}^2}{\text{MSE}}\right) \tag{1}$$

Where MAX is the maximum possible intensity value.MSE is the mean squared error. The MSE function is also defined by:

$$\text{MSE}=\frac{1}{m\,n}\sum_{i=0}^{m-1}\sum_{j=0}^{n-1}[I(i,j)-K(i,j)]^2 \tag{2}$$

Where I(x,y) is the intensity value at pixel (x,y) in the noiseless image, k(x,y) is the intensity value at pixel (x,y) in the noisy image.

2. Methodology

One of the most important parts to train a deep learning model is the dataset selection. The desired aspects of the dataset are to be large, noiseless information, and a dense depth map, meaning that all pixels have a depth value. The dataset that checked all the aspects is the Flying things dataset which is selected for training and to test/validate the model the Middlebury dataset is selected. As those datasets are used in stereo matching tasks the ground truth is a disparity map but can be converted into depth map by using the following equation.

To simulate real hardware, the distances are then normalized between 0 and 4095 (where 4095 is 18m) to imitate a 12bit analog to digital converter. The equation to convert disparity values extracted from stereo matching datasets is:

$$Z = f\frac{T}{d} \tag{3}$$

Z is depth, f is focal length, T is the distance between cameras, and d is disparity value.

Like many papers did, the noise is added artificially by summing a random image, Gaussian distributed, with zero mean and 255 standard deviations. The Gaussian noise was kept to test and validate the approach, but if another type of noise distribution is detected in future studies, the proposed model can be adapted.

3. Proposed Architecture

In high-quality traditional stereo matching algorithms after the matching step, the computed disparity is further processed by optimizing it by minimizing an energy function. The equivalent method for a CNN implementation developed for stereo matching tasks is the regularization steps which, usually, consist of encoder-decoder architectures to enhance and refine the disparity map. Supposing that the image from a TOF camera can be enhanced with the same method we propose the usage of stacked UNets with skip connections similar to PSMNet [13], but with 2D convolutions and residual bottleneck blocks. The proposed architecture, Table 1, is built upon a BasicConv which is a sequence of 2D convolution, batch normalization, and Rectified Linear Unit (ReLU) activation function.

Table 1. Proposed architecture.

LAYER/BLOCK	INPUT	KERNEL
BasicConv	WxHx1	Size=3x3,Kernels=128, Stride=1
BasicConv	WxHx128	Size=3x3, Kernels=128, Stride=2
BasicConv	W/2xH/2x128	Size=3x3, Kernels=128, Stride=1
Res_Unet	W/2xH/2x128	Stride=2
Res_Unet	W/2xH/2x128	Stride=2
Res_Unet	W/2xH/2x128	Stride=2
BasicConv	W/2xH/2x128	Size=3x3, Kernels=128, Stride=1
BasicConv	W/2xH/2x128	Size=3x3, Kernels=128, Stride=1
BasicDeconv	W/2xH/2x128	Size=3x3, Kernels=128, Stride=2

3.1. Implementation details

All codes were developed in python 3.7 in a Ubuntu 16.04 machine, OpenCV 4.1 was used to load/manipulate images, and Pytorch 1.0.1 was used to build and train the CNN. The proposed network was trained with logcosh loss, adam optimizer, a learning rate of 0.0001, and a batch size of 16. The loss function is given below:

$$Loss(y, y^p) = \sum_{i=1}^{n} \log\left(cosh\left(y_i^p - y_i\right)\right) \tag{4}$$

Where y is the ground truth value and y_p is the predicted value.

As the GPU memory is limited the images were cropped into smaller 92x92 patches to build the training batches. Also, all images were divided by 4095 to normalize them to values between 0 and 1.

The training section was not enough to complete an epoch (going through the whole dataset), as the dataset contains more than 20000 960x540 images it would take too long, and was trained for 13920 steps (about 4450 images). All training and validation were implemented on a Core i7 8750H, GTX 1050Ti 4GB with 16GB of RAM laptop.

4. Results and discussion

As described before, the Middlebury dataset was selected to validate the model performance. A total of 21 images were used for validation, similarly to the training step noise is added artificially by summing a random image following a gaussian distribution, however this time a seed was used to generate the same numbers, noisy images, making it fair to compare between checkpoints and to validate the model improvements during train season. Table 2 contains all the results with mean absolute error (MAE) in millimeters, MAE without considering the edges given in millimeters, PSNR in dB, and PSNR not considering the edges in dB.

Table 2. Validation performance results.

Image number	MAE [mm]	MAE without edges[mm]	PSNR[dB]	PSNR without edges [dB]
0	**757.8**	**553.0**	**23.5999**	**27.7506**
1	**664.2**	**548.1**	**25.7641**	**28.8376**
2	**604.8**	**527.7**	**27.1901**	**29.1806**
3	**901.8**	**674.5**	**21.7431**	**25.2678**
4	**606.6**	**487.4**	**25.6854**	**29.3118**
5	**581.4**	**444.4**	**25.3539**	**28.9093**
6	**603.0**	**576.1**	**27.9423**	**28.6548**
7	**684.0**	**544.9**	**23.5617**	**26.5834**
8	**610.2**	**520.8**	**25.7491**	**28.3964**
9	**608.4**	**506.4**	**26.3715**	**29.1668**
10	**831.6**	**523.2**	**21.9359**	**27.7333**
11	**770.4**	**550.4**	**23.7021**	**27.9718**
12	**781.2**	**586.3**	**24.1689**	**28.0893**
13	**648.0**	**546.0**	**26.0417**	**28.8634**
14	**676.8**	**569.0**	**25.0692**	**27.8267**
15	**536.4**	**440.3**	**25.7491**	**28.8105**
16	**583.2**	**499.3**	**27.0577**	**29.5701**
17	**770.4**	**602.2**	**23.4323**	**27.3206**
18	**835.2**	**646.2**	**22.9760**	**26.7951**
19	**603.0**	**484.1**	**25.7382**	**29.6685**
20	**680.4**	**546.4**	**25.2831**	**28.5535**

The general PSNR is 24.64dB and the general PSNR without edges is 28.11dB which performance is bellow when compared to other image denoise papers that achieve 30dB, however, it is a preliminary result to validate the concept of using deep learning to denoise depth images with 12bit resolution. Figure 2 illustrates, the CNN does filter noise at the cost of the image's structural integrity and shape.

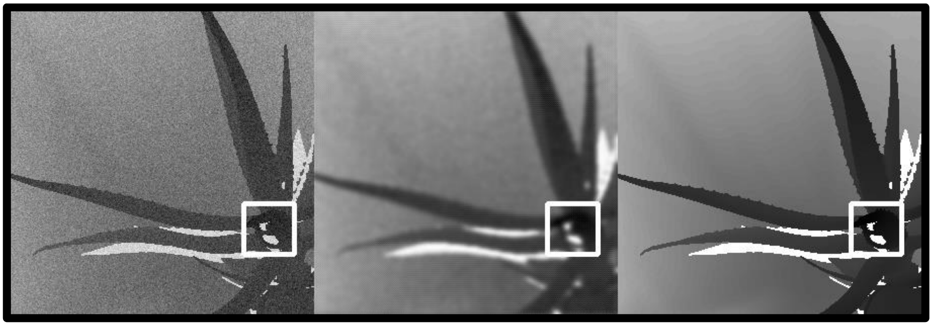

Figure 2. Noisy Image Input (left), Filtered Image (middle), Ground Truth Image (Right).

The decreased image output sharpness is probably caused by downsampling the resolution every time a convolution layer with stride 2 is used. This process reduces the required information for the reconstruction when a transposed convolution is operated, causing the blur effect in the output. The blur-like effect can be better observed in Figure 3, which is the detailed image of the white box in Figure 2.

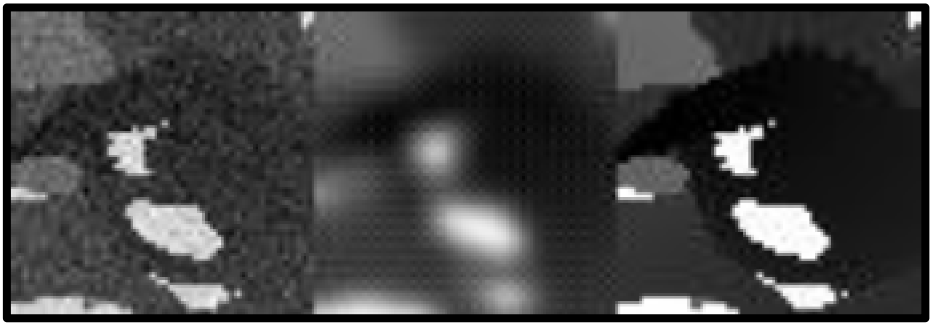

Figure 3. Detailed Images: Noisy Image Input (left), Filtered Image (middle), Ground Truth (right).

Subtracting the filtered image from the ground truth image and taking the absolute value of each pixel an error mask is made. Converting the error mask to depth error a heat map image is created to highlight regions with higher error. Figure 4 shows the depth error heat map results with and without edges.

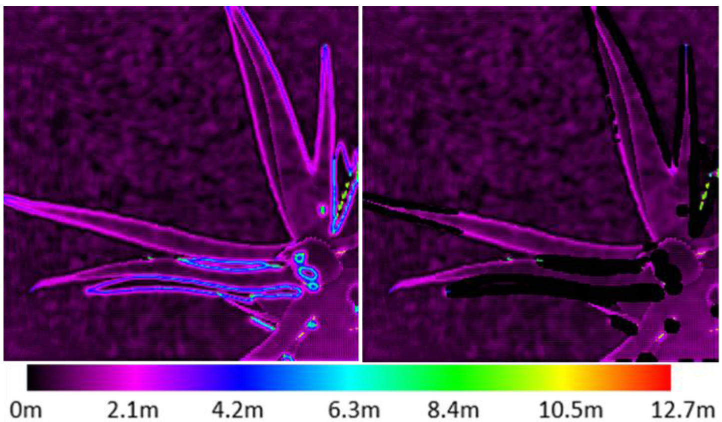

Figure 4. Depth error heat map image (Left), Depth error heat map image without edges(Right).

Figure 5 shows the depth error heat map of the same crop considered in Figure 3.

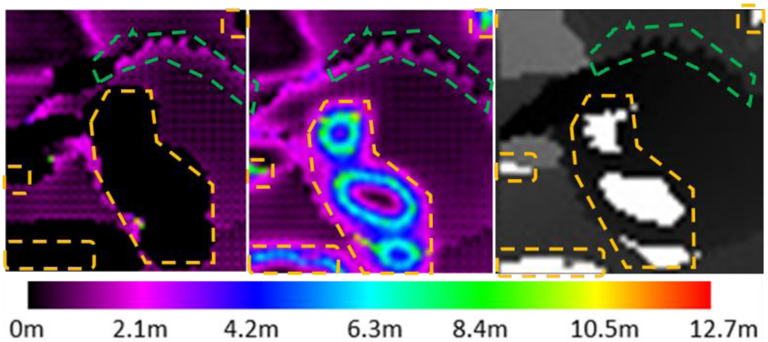

Figure 5. Depth error heat map image without edges (Left) Annotated heat map with edges (Middle), Annotated ground truth (Right).

The regions with dotted yellow lines annotation are the regions where the model performed worst, with errors ranging between 2,1m (purple), 4,2m (blue), and 8,4m (green). This type of event occurred in the transition from white parts, which depth correspond do 18 meters, to darker colors (which depth is near 0m) when analyzing the ground truth image. The error in the green region was smaller, ranging from 0 (black) to 2,1m. The model had the worst performance in regions with the transition to white spots. Because the Middlebury is a dataset extracted from stereo vision data, the white color is considered as a region where the matching algorithm could properly calculate the true depth, therefore considering the depth as the maximum value, which is 18 meters.

5. Conclusion and future works

In this work, the problem of ToF noisy depth images and the difficulty to acquire accurately noiseless depth images were approached, as a solution, a methodology using synthetic dataset and convolutional neural networks was proposed. The novelty of this work was to adapt the denoising approach which is commonly used for an 8bit image and apply it to 12-bit depth images. It was possible to simulate real ToF hardware by converting disparity generated maps to depth maps, and then normalizing the output to 12bit images. A CNN was trained with artificial images Gaussian noise using and then used for reducing noise in a real-world dataset with known ground truth.

The preliminary results pointed out that filtering performance did not achieve the state of the art performance and image output tends to blur. Spatial information seems to be lost during convolutions with stride 2, so a larger kernel to capture more spatial information could be a good option to implement and potentially reduce the blur. The worst performance was detected on the transition of objects where the depth gradient was high, and this hypothesis was confirmed by the removal of the information on the edges, which increased the performance of the final solution. Modifying the network do semantic segmentation, to detect these transition regions can be an option to improve the filtering capability.

The proposed architecture was able to mitigate some of the noise but it can be improved by optimizing hyperparameters and integrating semantic segmentation. The results also confirm the possibility of using only synthetic generated depth maps. Future works will also include the test of the model in a real scenario with a rear ToF camera to validate the proposed architecture. This will increase its applicability to ToF equipment for complex navigation scenarios, either indoor or outdoor.

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BIM Maturity Models Evaluated by Design Principles

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Abstract. The adoption and structuring of Building Information Modeling (BIM) is currently one of the main goals of many Architecture, Engineering and Construction (AEC) companies, but this scenario is still vulnerable due to the numerous simultaneous challenges related to technology, processes and culture. This promotes a sometimes wordy environment when developing the fundamental goal, definitions, steps, and attack plans for implementing BIM. Due to these circumstances, this study proposes an approach to assess readiness and maturity models aligned with the organization's strategic perspectives, discussing aspects of performance, applicability and usability. This work was developed from a systematic literature review of maturity models in 4 databases based on the ProKnow-C method. Its bibliometric analysis resulted in the selection of 23 articles, in which it was possible to evaluate 22 BIM maturity models and analyze them according to the structure of basic design principles supported by a descriptive and prescriptive purpose of use. Therefore, it is hoped that this research will allow companies in a simplified way to identify the maturity model that best fits the stage of the building's lifecycle in which it is inserted, supporting it in assessment as a contribution to the beginning of the digital transformation journey.

Keywords. BIM, Maturity, Readiness, Design Principles, Construction Lifecycle

Introduction

In the last few years, Building Information Modeling (BIM) has been a topic widely addressed, in both the area of academic literature as well as in real applications, since it has been seen by several organizations as a critical facilitator to implement digital processes in their businesses. In general, BIM implementation has been successful in both phases of the project and construction, although showing certain limitations in both phases of operation and maintenance [1].

The adoption of BIM includes more than equipment, human resource and technological infrastructure; it is also a systematic approach in a building’s life cycle [2]. In contrast, barriers still exist when implementing [3] BIM, such as significant expenses in educating professionals, as well as resistance to changes. Skills, training, learning curve and workflow comprehension are some of the main obstacles noted by specialists when executing BIM, specially in the design phase[4].

Consequently, it is necessary to measure progress development while BIM is being implemented. An excellent tool for such responsibility is Maturity Models (MM), which performs on all the stages of work: planning, execution, control and action. MM is a technic that has been adopted to evaluate and measure different aspects of processes or

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organizations. It can provide a more organized approach for a company, as well as applying its business in a more systematic manner. While it provides a method to control processes and benchmarking, it also supports evaluation of the progress, aligned with objectives, as well as comprehension of strength, weakness and opportunities of the company [5].

Even though MM shows great popularity, few study applications exist to discuss and prove MM's usability [6]. A verification framework through design principles (DPs) is needed to assess the application domain and purpose of using the models to lead to a change in the level of organizational maturity.

Having this perspective in mind, this project finds an incentive in presenting an evaluation of 22 readiness models or maturities that already exist, with the intention of supporting companies into identifying which of those MM will be more suitable to adopt and implement BIM, focusing in creating a trustable information's management.

This article will be organized in the following approach: Section 1 provides a background for construction's life cycle, relevance of MM and the structure of DPs. Section 2 will present a methodology in order to select possible MM. Section 3 addresses partially the evaluation and development of this project. At last, section 4 will focus on the main conclusion points, as well as suggestions for future researches on the theme.

1. Background

This section will briefly present the context in which this research is being implemented, separating into three topics: construction's life cycle, maturity models and design's principles.

1.1. Construction Lifecycle

The basic premise of BIM is the collaboration among different participants during the life cycle of a construction, in a way that the extraction of data can be update instantly and utilized by all the members [7].

The modelling of information includes the flow of data, information and knowledge throughout the business' life, in which it develops into three phases: project, construction and operation; those can also be further divided into subphases [8]. Figure 1 represents these understanding and contextualization of aligning this study.

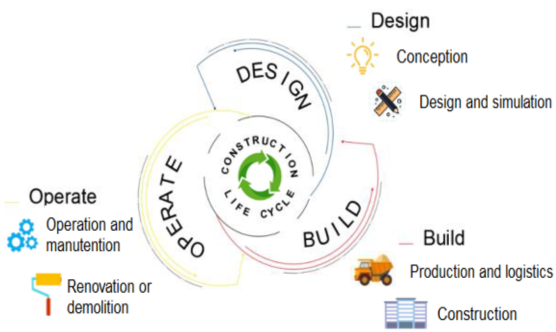

Figure 1. Construction Lifecycle.

While each cycle's phase is formed by different activities, they all are complementary to each other. Establishment and application of BIM provides specific advantages for each of those segments:

Design: Considered the first phase of the cycle, with the benefits of modeling a more accurate visualization during earlier stages of the project; automatic corrections of elements in the model when changes are made in the project; automatic formation of 2D drawings; easiness in interdisciplinarity with greater briefness; automatic extraction of quantitative data during the project's phase; improvement in energy and sustainability analysis process [9].

Build: This step is based on synchronizing the planning and construction management with model's objects in the phases of acquisition, project and construction; discovery of physical interferences between elements of the edifice or omissions before executing the construction; quickness in processing changes in the project; possibility of using the project's model as base for prefabrication and support in the implementation of the lean construction methodology [9].

Operate: It involves services such as maintenance, reforms and demolition. With BIM it is possible to provide a better management for operation of systems and assets of the building, once it is a multifaceted problem that involves costs, installation management, human resources, actives management and code compliance, affecting different concerned parties in different manners [10].

When there is an efficient interoperability along the life cycle of the project, supported by BIM, it is possible to have a better management, as well as support the users to improve sustainability of projects [11]. After elucidating symbolically all the phases of a project e the various benefits provided by the implementation of BIM in the organization, the next topic to be treated will further discuss the relevancy of a MM oriented to the phases of the life cycle of the construction.

1.2. Maturity Models

Despite being characterized as "step-by-step recipes" [6] that simplify reality and lack empirical foundation, maturity models are based on the assumptions of predictable patterns and represent theories about how organizational capacities evolve gradually, according to an anticipated, desired, or a logical maturation approach [12].

BIM implementation is directly associated with gradual and continuous improvement in quality, usability and predictability, conform the current state of the company that can be assessed through MM to identify what improvements can be implemented in the processes in order to achieve real benefits to the business [8]. Moreover, it is important to point out that the organizational structure and maturity level of a company possess significant influence on the development of its processes and execution [13].

Years later [14] , it has been proposed a structural equation model that tested the casual relationship among various factors that constitute the general maturity of BIM. As a result, the authors found empirical evidence for the correlation between process management and technology management. Both factors had a positive and significant impact on BIM's information, management and overall maturity.

Literature also reveals assessments of the impact of BIM maturity on the performance of companies, since BIM is strategically applied in processes, infrastructure and people. It was then concluded that there is a positive impact of readiness models in BIM [15]. Above all, the relationship between acceptance and technological readiness is substantial, with the latter being the key for successful acceptance of the former [16]. Consequently, both factors are essential for evaluating BIM implementation on a company.

The establishment of maturity levels and BIM performance when providing metrics for the pragmatic use in the academy is like attending the necessity of the market, in the same way that appointing a project to attend the necessities of a client is for an industry [17].

Thus, it is perceptible the added value in adopting a MM or readiness models (RM) as tool to measure the development level and BIM implementation, as well as capable of being utilized as a guide for goals and strategic objectives of the organization. However, countless models were proposed throughout time, with criteria that can be adopted by several factors, according to regionality, culture and segment of the business, requiring a structured assessment that will be addressed in the next topic.

1.3. Design Principles

In the need to "measure" the level of organizations, numerous MM were developed without properly understanding what criteria should contain. Thus [6], it was proposed a pragmatic and coordinated approach initially guided for the BPM (Business Process Management): the DPs. However, it has potential for application in any model and domain, as it serves as a checklist for MM verification and evaluation, with descriptive and prescriptive use; or even in order to assist in the development of new models (Basic Principles). For clarification, Figure 2 provides definitions and purpose of MM [6]:

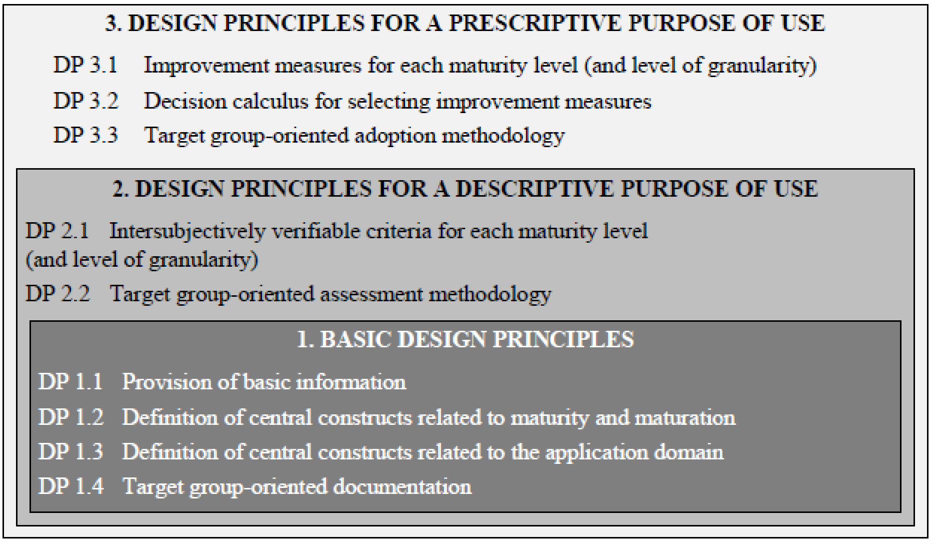

Figure 2. A framework of general design principles for maturity models.

Descriptive Model: Intended to diagnose [18] or assess current capabilities against certain criteria [19].

Prescriptive Model: Identify levels of maturity desired and provides guidelines on improvement measures [18], which may also suggest specific and detailed action plans [19].

Comparative Model: Allows internal or external comparative assessment, based on robust assessment data, which its levels can be compared between similar business or organizations [18].

For each principle, requirements were defined for analysis in a timely manner aligned with MM's purpose, aiming at the objective, rationale, applicability, usability, maturity levels, selection of criteria, evaluation of variables and the listed procedures.

2. Methodology

This article was developed from three main and distinct methodological structures, which are: Exploration, development and evaluation.

Figure 3 represents the methodological approach for analyzing maturity models and assessing the descriptive and prescriptive use in conjunction with the building's life cycle.

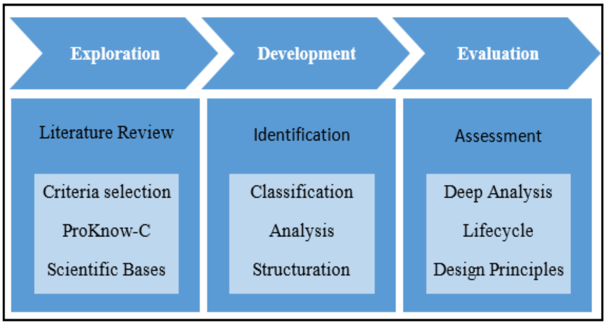

Figure 3. Methodological Structure.

Step 1 – Exploration: In order to identify maturity and readiness models existing in a refined way, it was adopted the Proknow-C methodology (Knowledge Development Process – Contructivist) [20], in which consists in a revision od systematic literature based on 10 steps with investigations in 4 research bases. Due to representing and honor different geographic regions, the 4 bases selected were ASCE, Science Direct, Scopus and Web of Science. For the development of this methodology, there was an on the criteria of terms, types of documents restricted to technical papers and articles, as well as publication period limited from 2010 to 2019, written in English. The search provided 436 initially; however, more than the criteria cited above, there was the removal duplicated articles, eliminating unaligned titles. Hence, the author database was built, with the minimum number of citations delimited to 5 and resulting in a repository with 23 articles. Among those, 22 models of maturity or readiness in BIM were found.

Step 2 – Development: In order to understand the models extracted from step 1, the development phase consists of identifying the scope, dimensions and maturity levels of the MM obtained. This preceding analysis was essential to support elements of comparison for the next stage, as well as to observe the evolution of the models in a temporal and focused approach. Moreover, the rationale and bibliographic review for this project was structured at this step, basing them on complementary studies to the MM and using the author database previously built.

Step 3 – Evaluation: In order to assess the MM / RM, criteria were established based on the Designed Principles [6], focusing on the descriptive and prescriptive approach, since it is comprehended that an in-depth analysis is of great importance for its application in an organization. Furthermore, in order to comprehensively classify the evaluation models, it was decided to associate the MM / RM with the phases of the building's life cycle: design, construction and operation.

These criteria made it possible to obtain a holistic view as well as observe the individual characteristics of each model as a guide to the selection and definition of an MM in an organization, regardless of its strategy and field of work.

3. Case Study: Identification

In order to identify MM and their main characteristics, the following elements were formerly analyzed: name of the MM (when available), maturity levels and domains. It is worth mentioning that each author adopts a nomenclature, which may be attributes, factors, criteria, areas, chapters or skills. Table 1 contains a partial extract that provides seven models, from the 22 evaluated, to illustrate how the identification stage was developed.

Table 1. Extract of BIM Maturity and readiness models.

Model	Model/ Research name	Maturity levels	Domains
MM1 [21]	TAL (The Accepted Level)	Concordance/ Discordance	Two domains: technical and economic criterias
MM2 [22]	BIM- CAREM (Capability Assessment Referece Model)	0 - Incomplete BIM / 1 - Performed BIM / 2 - Integrated BIM / 3 - Optimized BIM	Six attributes: Performing BIM, BIM Skills, BIM Collaboration, Interoperability, Corporate-wide BIM Deployment and Continuous BIM Improvement
MM3 [23]	BIM Benchmarking model	Very poor/ Poor/ Average/ Good/ Very Good/ Excellent	Three areas: BIM process, BIM product and Measures of good practices
MM4 [24]	Building Owner BIMCAT (BIM Competency)	0 - Nonexistent/ 1 - Initialized/ 2 - Managed/ 3 - Defined/ 4 - Quantitatively managed/ 5 - Optimizing	Three areas: Operational, Strategic and Administrative
MM5 [25]	VDC Scorecard	Conventional Practive/ Typical Practice/ Advanced Practice/ Best Practice/ Innovative Practive	Four areas: Planning, Adoption, Technology and Performance.
MM6 [25]	BIM Maturity Matrix	A - initial-ad hoc/ B - defined/ C - managed/ D - integrated/ E - optimized	Three areas: Process, Polits and Technology
MM7 [26]	BIM capability assessment	1 - Not influential at all/ 2 - Slightly influential/ 3 - Quite influential/ 4 - Very influential/ 5 - Extremely influential	Four criteria categories: Competence, Capacity and Resources, Culture and Attitude, Cost

In the analysis made prior to the selected articles, it was possible to observe that many of these already made comparisons between some MM disseminates in order to evaluate some specific elements. Nonetheless, only MM related to BIM were assessed, since several of them were related to other segments, such as IT and supply chain. Moreover, none of the articles mentioned or evaluated MM / RM following the premises of the design principles.

It is noteworthy that some models allude to BIM capacity and its competences, which can be considered as a development of maturity. Regarding the maturity levels, there is a consensus between 4 to 6 levels, with some exceptions. When analyzing domains, it is noticed that the criteria have variability among them, but with an approach directed to processes.

3.1. Assessment

At this stage, there was an attempt to evaluate and classify the MM / RM according to the structure of the DPS. The extract of the detailed analyzes and evaluation from the seven models, which are presented in Table 2, contains the scope of the MM (descriptive, prescriptive or comparative), the structure of the model, a proposed methodology and existence of measures to guide the development of maturity levels in the organization.

It is important to emphasize that each maturity model observed possess a different focus, which makes evident the need to have a coherent diagnosis of the company to adopt the measures and changes necessary and appropriate to the organization. It was found, in relation to the scope of the models, that 90% had descriptive characteristics. This means that they are able to measure and diagnose the level of maturity or readiness of the organization. Only 14% reflect a prescriptive method, which means guidelines aimed at increasing the level of maturity.

Hence, Figure 4 uses a Venn Diagram to address how the models evaluated are subdivided according to the phase of the life cycle in which they are incorporated. It is noticeable that the design phase (18) is the one that has more interfaces and better elaborated strategies, for the adoption of BIM. In the sequence, there is the construction phase (16) and operation phase (11).

This analysis indicates that BIM still has a greater bias specifically at the beginning of studies and projects, suggesting that, frequently, the information does not follow the building's life, and it is not effective in its entirety or even expensive.

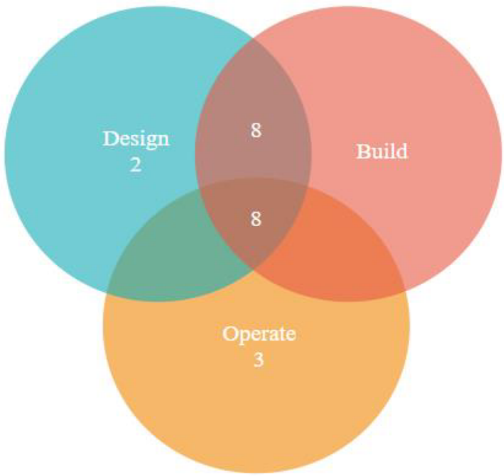

Figure 4. Construction Lifecycle Venn Diagram.

Table 2. Extract of Maturity and Readiness models from the perspective of Design Principles.

Models	**1.1**	**1.2**	**1.3**	**1.4**	**2.1**	**2.2**	**3.1**	**3.2**	**3.3**
	Provision of basic Information	**Definition of central constructs related to maturity and maturation**	**Definition of central constructs related to application domain**	**Target group-oriented documentation**	**Intersubjectively verifiable criteria for each maturity level**	**Target group-oriented assessment methodology**	**Improvement measures for each maturity level**	**Decision calculus for selecting improvement measures**	**Target group-oriented adoption methodology**
MM1[21]	PoU: descriptive (assessment that identifies the organizations BIM readiness)	2 maturity levels; 2 criterias; 23 subcriterias	Terms and definitions are available	Report	Textual descriptions of dimensions and attributes	No assessment questionnaire available; experiences from assessment is given	Not applicable	Not applicable	The level of acceptance is measured without focus on a specific phase in the life cycle
MM2[22]	PoU: descriptive (assessment that identifies the organizations BIM readiness)	4 maturity levels; 6 attributes; 16 attributes outcomes	Terms and definitions are available	Report	Textual descriptions of capability levels and attributes	No assessment questionnaire available; experiences from assessment is given	Not available	Not applicable	The results were positive in the design phase
MM3[23]	PoU: descriptive (assessment that identifies the organizations BIM maturity); comparative (benchmarking against other organizations)	6 maturity levels; 3 indicators; 17 sub-indicators	Terms and definitions are available	Report	Textual descriptions of level maturity, indicators and sub-indicators	No assessment questionnaire available; assessment based on literature review and case studies	Not available	Decision calculation only for diagnosis	Approach to the design and build phases
MM4[24]	PoU: descriptive (assessment that identifies the organizations BIM maturity)	6 maturity levels; 3 areas; 12 categories	Terms and definitions are available	Report	Textual descriptions of areas	No assessment questionnaire available; assessment based on literature review	Not available	Decision calculation only for diagnosis	Focus exclusively on postconstruction operations
MM5[25]	PoU: descriptive (assessment that identifies the organizations BIM maturity); prescriptive (prescribe actions that could improve maturity);	5 maturity ranges; 4 areas; 10 divisions	Terms and definitions are available	Report	Textual descriptions of maturity levels, areas and subdivisions	Assessment questionnaire available online; experiences from assessment is given	Available	Decision calculation only for diagnosis of the current level	Approach to the design, build and operate phases
MM6[25]	PoU: descriptive (assessment that identifies the organizations BIM maturity); comparative (benchmarking against other organizations)	5 maturity levels; 3 areas; 10 competencies	Terms and definitions are available	Report	Textual descriptions of levels maturity and competencies	This model has become a consulting website offering services for individual or organizational evaluation	Available	Not applicable	Approach to the design, build and operate phases
MM7[26]	PoU: descriptive (assessment that identifies the organizations BIM capability)	4 criteria categories; 11 second-tier criteria; 28 sub-criteria	Terms and definitions are available	Report	Textual descriptions of criterias	Assessment questionnaire available; experiences from assessment is given	Not applicable	Decision calculation for criteria selection	Not applicable

4. Conclusion

Initially, BIM has been adopted in individual departments, such as civil and architectural projects restricted to organizational management functions. However, it is understood that a more assertive management aims to align organizational requirements based on policies, technology and processes, to ensure the financial health of any organization.

It is noticed that a few companies in the AEC sector operate in all phases of an enterprise, that is, they are inserted in only one or two stages – at most – not having their cycle from begin to end complete. That happens because, usually, the team that makes the project does not always build it, much less perform maintenance, renovation or demolition of such. Therefore, it is understood that the demand and application of BIM can happen in different manners, consequently making different types of implementation.

Consequently, this article sought to present the characteristics and assessment of MM / RM found so far in a succinct and punctual manner, according to the aspects of design principles on what should be contained in an MM. This critical assessment can assist and guide organizations to select the methodology and model according to the stage and life cycle to which it belongs, reaching the objectives proposed in this work.

It is important to note that this implementation stage (also known as digitalization) is only a beginning for digital transformation. Stages of integration and optimization will still be needed on this journey. However, when there is an assertive direction in conjunction with the organization's strategic alignment, the adoption and structuring of processes, technology and culture will happen in sync.

Limitations exist in this article, such as blocked access to some publications and the restriction of pages for submission. Still, as it is not part of the scope of this work, identifying and comparing the criteria individually would bring a more holistic view of the approach of each MM, thus making an analysis based on multicriteria methods as a suggestion for future works.

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A Discussion on Current Issues for Semantic Interoperability in an Integrated Manufacturing System

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Abstract. Digital manufacturing has been challenged by the manufacturing industry to rationalise different ways to connect and to exchange information and knowledge across the manufacturing systems. One of the main pillars of the Industry 4.0 concept is the horizontal and vertical integration with intelligent and self-adaptive systems. For this to be possible, the manufacturing industry applies an extensive range of software tools to aid its activities, such as SCADA, MES, ERP, 3D CAD, CAM, and so on. Individually, each one performs its function to support the manufacturing process. However, these software tools do not have an effective integration and interoperation, since they present different database structures, variables that have the same information with different names and data structures, and closed systems. Thus, it has been identified semantic interoperability issues (misinterpretations and mistakes) in view of the information heterogeneity from multiple perspectives and their relationships across the manufacturing process. In this context, this paper aims to present a discussion of interoperability issues across the manufacturing systems, as well as to introduce possible solutions according to the related works. a holistic approach is critical factors for long-term competitiveness solutions. The literature points out that the solution to this problem may be in the application of semantic technologies. These have the potential to provide solutions that are more comprehensive than the industrial approaches that have been applied through the formalization of information so that knowledge can be shared among multiple domains.

Keywords. Manufacturing System, Semantic Interoperability, Formal Models, Semantic Reconciliation.

Introduction

Nowadays the companies need to answer quickly to the external changes concerning the stakeholder's needs[1]. In order for this to be possible, the manufacturing industry applies a varied range of software tools to support their activities. Some of the main tools are Product Lifecycle Management (PLM), Enterprise Resources Planning (ERP), Supply Chain Management (SCM), Manufacturing Execution Systems (MES), Supervisory Control and Data Acquisition (SCADA), and specific machine control systems [2]. All these systems together sustain the manufacturing process as a whole, from the highest planning level to the shop floor. To guarantee the highest productivity with a lesser

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amount of loss and rework, it is necessary that these systems operate in an integrated manner.

For an integration of systems to exist, these must exchange and share information. These systems share thousands of heterogeneous information and knowledge from multiple groups within and across institutional boundaries [3][4][5]. For example, the wrong identification of an item in a lot of parts with defects could cause the need for a recall in the automotive industry. The lack or low quality of information must generate several types of damages (time, quality, financial loss, and so on).

There is an extensive range of systems available to the companies and each one has its own structure and language since each one was developed by diverse producers. All tools are created and optimized to aid a specific part of the manufacturing system process. In diverse situations there is not a single possibility of integration of the system, causing the extreme dependency on human participation and interpretation of the process. When the integration was predicted, it is usually based on specific patterns, that might not even be shared by the other applications. According to [2] the application of patterns of industrial communication can help, but nowadays these tend to be focused on few domains and are not adequate for the most variated layers of knowledge and information that need to be managed during the manufacturer.

The knowledge from every part of the process and development of the product can be formalized, generating the representation of the same object coming from multiples points of view, as well as different representations of similar concepts [6][7]. [8] defines the multiple representations of an artefact or concept as "semantic heterogeneity", which is an obstacle to the process of manufacture. To solve this problem it is necessary to realize the process denominated "semantic reconciliation". This process s usually realized manually by the programmers on the moment of integrating different systems, or by the machine operators themselves during the manufacturing. In order to realize this process in a more automated environment, the companies are investing in computational network emerging technologies, such as the Semantic Web [11][12][13].

The Semantic Web is, in synthesis, a network of relationships between entities. However it's objective is to operate as a virtual model of the object or process in the way that every part involved in the manufacture, machine or human, can be able to access the requirements of the product and process that is being produced in a common environment. The systematization of the knowledge, denoted interoperability, is one of the main aspects of the Semantic Web and is promoted through the ontological integration, with the goal to create a common ontology to every source of knowledge in an environment of information exchange [14][15][16][17].

An ontology is an explicit and formal specification of the characteristics of a term in a domain, as well as the relationships between these terms [9]. In computational systems, an ontology is a data structure where characteristics of certain entities or environments are stored, as well as the relationships between different characteristics of the same entity or different entities, registered in a machine-readable format. [8][10]

In this context, this article has the objective to discuss the possible application of ontologies to solve the problem of semantic interoperability, present on the information systems, in an integrated manufacturing system to minimize the misinterpretation and to promote the automatic semantic reconciliation between these systems.

Chapter 2 presents a specific view about the integration problem in manufacture aid systems, and where the system based on ontologies could be applied. Chapter 3 presents the main topics that indicate the path to the delimitation of the problem, and possible solutions, according to related works present in the literature. Chapter 4 promotes the discussion of a possible solution based in ontologies for the semantic interoperability problem in the integrated manufacturing system.

1. Problem Statement

"An ounce of information is worth a pound of data. An ounce of knowledge is worth a pound of information. An ounce of understanding is worth a pound of knowledge" [18]. Figure 1 presents the view of a conceptual integrated manufacturing system model, associated with the levels of content present on the human mind according to [18]. These levels are:

- **Data Level -** it is composed of symbols that represent the properties of objects and environments. These are raw, and can exist in many forms, usable or not [18]. It's the level where the sensors, transducers, actuators, motors and etc. are present;

- **Information Level -** it is the level where is present the data that have been given meaning through relational connections [18]. Comprehend the layers of control – composed by PLCs and other controllers – and SCADA / HMI, as well as the layers, corresponding to the systems of corporative management, such as MES and ERP. In this level the data are already refined and have a local practice application, that is, in the process that they are inserted;

- **Knowledge Level -** it is a collection of information that has the intention to be useful [18] not only for the process in question, but also to the other processes inside the same company, or even other companies. In the integrated manufacturing system, in general, there is no system applied to this level of content;

- **Understanding Level -** this is the process that makes it possible to create new knowledge through the knowledge obtained early. The difference between knowledge and understanding is the same as memorizing and learning [18]. In this level occurs the decision-making on a company level, where the managers use all of the knowledge generated to parametrize all the processes in the way to direct the whole company to attend to reach the goals planned, as well as planning new goals.

Figure 1 also proposes two distinct levels of integration present on the processes of operation and production in manufacturing:

- **Vertical Integration -** it is integration between the different layers of systems inside the same manufacturing process;

- **Horizontal Integration –** it is the integration among the distinct processes that compose the integrated manufacturing system.

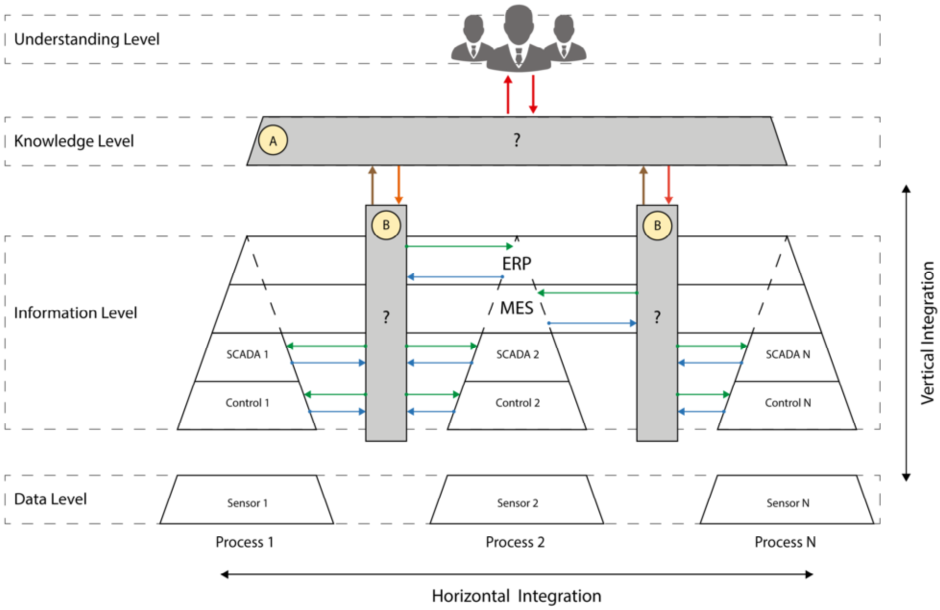

Figure 1. Elements of a Conceptual Integrated Manufacturing System.

Figure 1 shows ideal conditions, where all the systems operate together and information traffics in all the ways. However, this doesn't happen in reality [3]. The actual manufacturing systems have some kind of integration, but this is based mostly on industrial protocols, and they can reach more than two layers of information. [19] mentions that although industry has responded to the interoperability challenges with collaboration interfaces and integration mechanisms, these approaches may become unsustainable with the huge variety of system architectures in development.

In detail A of Figure 1, it is possible to verify that there is no specific system to aid the level of knowledge, that is, applying the information captured from the processes. This happens because the functions of these levels are completely attributed to the managers and operators, once that the actual systems, in general, does not have any automation or intelligence created to aid this process.

In order to create a tool for the automation of the knowledge level, it is necessary that all the information and knowledge originating from the process to be available. The detail B of Figure 1 points the need for an element in the system to unify all the knowledge and information coming from the most diverse layers of the integrated manufacturing system. Yet, in this process, two problems may appear: I – the same information \ variable being applied to different components (semantic problem) and II – different variables \ information being applied to the same component (syntactic problem) [20]. These problems are known as semantic heterogeneity and are problems of the semantic interoperability.

In this context, *is it possible to propose a vertical and horizontal integration intelligent system in order to support all phases of a manufacturing process, overcoming the semantic interoperability obstacles?*

2. Related Works

This section presents the main topics contained in related works of the current literature, that are in conformity with the research objective, in order to enlighten the path to delimiting the problem and finding a possible solution, as well. These topics are (i) Vertical and Horizontal Integration in Manufacturing Systems; (ii) Semantic Interoperability Concept; and (iii) Ontology-Driven Interoperability.

2.1. Vertical and Horizontal Integration in Manufacturing Systems

The companies must answer quickly to the product and manufacturing changes in order to be in a continuous evolution [3]. Industry 4.0 concepts have been applied to increase the level of horizontal and vertical integration on the manufacturing systems through Information Communication Technology [20].

The horizontal integration is presented by [2] as the cooperation between one company and other related companies. Cooperative and competitive relationships establish an ecosystem where information, finances and materials can move continuously in cooperation. From the perspective of the system, the integration includes the interconnection of the elements of value, such as equipment, people, organizations, processes and products. The composition of the value networks connects and creates values between the elements. Due to the interactive unions between the elements of value, the companies can generate advances and innovations. This creates the opportunity to develop new business' models [21].

The vertical integration is the integration of elements that are important to the company itself, such as the people, equipment and products in a production line or factory. The vertical integration also includes the tasks of integration, such as marketing, sales, services and procurement [22]. A manufacturing system can unite the activities of manufacturing in a value chain through the cyber-physical systems [21]. The vertical integration allows the holistic view of the manufacturing process and makes it react to the customers' needs as fast as possible [23].

2.2. Semantic Interoperability Concept

According to [24] the mistakes and miss-interpretations during the steps of design and manufacture correspond to 85% of the final cost of the products. In order to guarantee the optimization and cost reduction, keeping the same quality, the share of information during the different steps of the development of products and manufacture must be realized in an efficient manner [25].

[26] defines this situation as a semantic interoperability problem, where the meaning associated to the captured information must be shared between the different domains of a system without losing quality (meaning and intent) during the exchange process. The most common method to guarantee the lossless exchange of information during processes has been the definition of common information models [27] [28]. In order to accomplish this goal, the construction of ontologies has shown itself a viable solution on the formalization of these common information models, as well as in the sharing of formal information through the manufacture processes, what also provides the increase of the presence of the knowledge in the application domains [28] [29].

[3] presents that even though technical standards such as ISA-95 (IEC/ISSO 62264) provides a very useful reference towards the interoperability as a tool for manufacture, it shows the limitations by the lack of semantic consistency on its operation/implementation. [30] illustrates the problem of misinterpretation between the users of ISA-95, identifying 83 errors in a simple real-world example, and demonstrating how these could be avoided if formal semantic approaches were used. [3] reinforces that representing information in a robust and consistent interpretable manner, in the way that it can be shared with trust, is a substantial problem.

2.3. Ontology-Driven Interoperability

The principles and methods for the representation using ontologies were developed in the field of Artificial Intelligence to ease the share of knowledge and reuse among people and application systems [31]. The ontology was developed to provide a semantic that can be processed by machines in information sources that can be communicated through systems and humans [32]. The concept of ontology has its origin in philosophy, where it means a systematic explanation of being [33]. In the last decade, the concept of ontology has show itself more significant for the Intelligent Information Integration, Internet Information Retrieval, Knowledge Management and Semantic Web. The reason for this expansion is the promise to provide a common understanding and sharing inside a specific domain [34]. Nowadays, the ontology is recognized as an important technology to face issues of semantic interoperability [17].

Several research works have been carried out in the field of engineering applying ontologies to solve specific semantic interoperability issues. [35] researched a framework to semantically support the interoperability between design between product design and manufacturing. [36] created information mapping to translate information from the product design to manufacturing. [37] defined a model of manufacturing engineering that can be applied to enable the exchange of information between companies and between multi-disciplinary teams of design and engineering. [38] proposes an ontological model to evaluate the adesion of existing production systems to engineering changes requests or new products in the context of the automobilistic industry. [39] presents a semantic model to support the calculation of energy efficiency indicators in welded-assembly processes.

The combination between Ontology Web Language (OWL) and the Semantic Web Rule Language (SWRL) was employed to solve different issues in representing constraints in formal models. Works such as [40] [41] [42] and [43] explore the combination of OWL and SWRL. Rules in SWRL offer a powerful layer of axioms that cooperate with OWL-based ontologies in order to provide the semantic enrichment.

3. Discussion

In order to meet the request of the Industry 4.0 to the connection and integration between processes (vertical) and companies (horizontal), it is necessary, before, to step back once. It is necessary to organize and formalize the information and integrate the internal processes, in the way of assuring the quality and confidence of the information that will be repassed to the partner companies. For this to be possible, the integration could be analysed at principle under the optics of processes and operations, dealing with the vertical integration as the layers of systems in each process and the horizontal integration as the continuity of information and knowledge between every parallel process in the manufacturing.

The tools proposed by the literature when applied to other domains of knowledge has shown themselves very effectively. Analysing the problem of the integration of the layers and processes as a problem of semantic interoperability it is possible to verify that, in an integrated manufacturing environment, with the problems of information traffic, the ontologies seems to be an interesting path to the solution.

However, the development process of this system would require the integration of several domains / disciplines of knowledge. Examples are mechanics, electrics and automation that are applied to the machines, chemistry for the processes, materials engineering, production management, business, marketing and many others. This requires a multidisciplinary team to work together upon creating manners of gathering all the information and knowledge involved in the manufacturing process in a single source. One of the obstacles that this platform will have to overcome is how to ease the transdisciplinary interaction among all these areas.

To realize formal modelling in ontology, adequating the variables correctly in every step of the process for them to contribute with a unified common model, has the potential to turn the information accessible to every part of the manufacturing process. Additionally, once the models are organized and structured, a new horizon is open for the application of techniques from semantic interoperability, enabling for example to create formal rules and establishing relationships among these entities in order to aid the decision making and generation of new knowledge.

With the knowledge formalized and accessible to every layer of all the production processes, it would be possible to minimize the errors, integrating the different layers and levels of information, reducing drastically (or even extinguishing) the necessity of the operator in some cases. In this manner it would be possible also to share information with partner companies with trust, enlarging the productivity of the ecosystem as a whole.

Figure 2 presents the possible conceptual model of the integrated manufacturing system with the ontology-based system applied (Detail A of Figure 2). This environment would integrate and reunite the information coming from every system of manufacture aid through the semantic reconciliation technologies (Detail B of Figure 2). This way, beyond promoting the horizontal and vertical integration inside the company, the system would have all the knowledge of the process formalized and unified, improve the decision-making on the level of understanding, and possibly reducing drastically human mistakes on the integration of the systems.

However, it is necessary to emphasize that the application of ontologies to industrial processes are recent and in development. The technologies of semantic interoperability require a specialist for the implementation and are made in manual processes, non-automatized, making this procedure relatively costly.

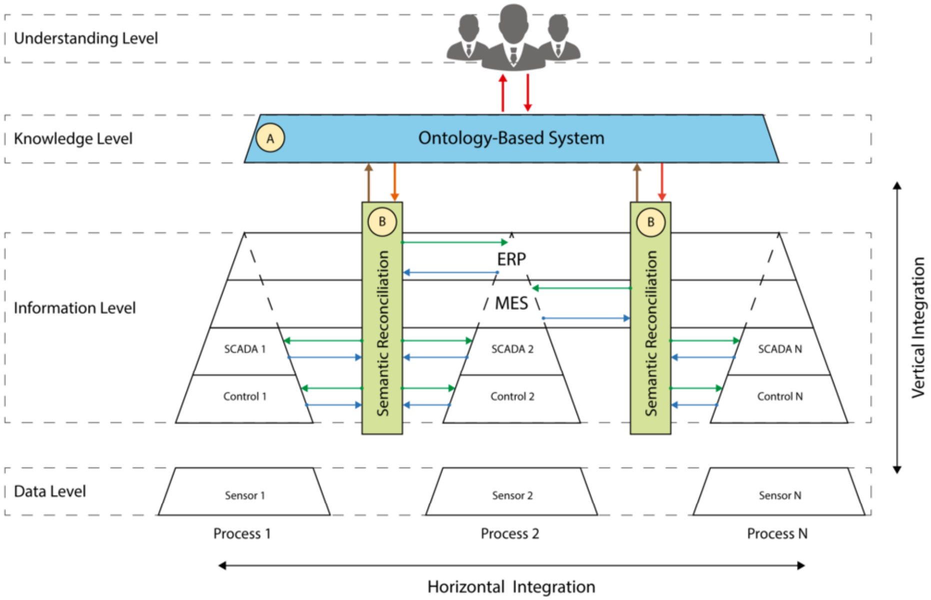

Figure 2. The conceptual solution for the interoperability problem in an Integrated Manufacturing System.

4. Conclusion

This article presented research directed to identify the problems on the flow of information in an integrated manufacturing system and possible solutions explored by the literature. This work is pertinent as an initial approach to the problem, showing the direction to be followed in future research. However, many challenges and problems need to be solved with horizontal and vertical integration. The ontologies and semantic interoperability tools have shown as a relevant solution for the problem of information integration to the layers of software and processes.

Additionally, the application of these technologies is not trivial and requires a holistic view of the whole manufacturing system, with specialists dedicated full time for the modelling of the knowledge structure. But, the integration of these processes can reduce drastically the necessity of human interference, increasing the confidence and quality of information, impacting directly on the productivity of the company.

As a future work of this research, it is necessary to carry out a deeper review of the literature through a systematic literature review, in order to define and validate the state-of-art in the related topics. The authors suggested as the main topics to the systematic literature review to explore semantic interoperability subject, integrated manufacturing systems, horizontal and vertical systems integration and other related areas. Additionally, the authors suggest the application of the main concepts identified in the literature review in experimental real cases.

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Neural Network with Specialized Knowledge for Forecasting Intermittent Demand

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Abstract. Demand forecasting is an essential part of an efficient inventory control system. However, when the demand has an intermittent or lumpy behavior, forecasting it becomes a challenging task. Several methods have been developed to solve this issue, but nonetheless, they only consider the information about the occurrence of demand, failing to assess the drivers of the data behavior. With the current digitalization of the industry, more data is available and, therefore, the chances of finding a causal relationship between the available data and the demand increases. Considering that, this paper proposes a single-hidden layer neural network for forecasting irregularly spaced time series with attributes conveying information about the past demand, seasonality of the data and specialized knowledge about the process. The neural network proposed is compared with benchmark neural networks and traditional forecasting methods for intermittent demand using three different performance measures on actual demand data from an industry operating in the aircraft maintenance sector. Statistical analysis is conducted on comparison results to identify significant differences in the forecasting methods according to each performance measure.

Keywords. Demand forecast, intermittent demand, neural network, specialized knowledge

Introduction

There are a variety of challenges for every area in the implementation of the smart manufacturing, or smart production factory, and overcoming them requires the collaboration of different disciplines, both technical and social disciplines. The 4th industrial revolution focuses not only on making machines intelligent with sensors and IoT (Internet of Things) but also on automating and improving decision-making processes [1]. One of these processes is inventory control, it can have its efficiency improved thought the use of Industry 4.0 technologies [2].

Inventory control is essential for the company's competitiveness in any market [3]. One of its main components is demand forecasting. Due to its importance, several forecast methods have been developed over the years. These methods yield their best results depending on the demand behavior. The demand behavior can be divided into

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four types, as follows: (i) erratic, a pattern that has a high demand size variability and does not have many zero-demands; (ii) smooth, it has a low demand size variability and few zero-demands; (iii) intermittent, a pattern that has many zero-demands and a low demand size variability; and (vi) lumpy, it has many zero-demands and a high demand size variability [4].

Different methods centered on lumpy and intermittent demand have been proposed in the literature. The single exponential smoothing (SES) [5] was commonly used to predict the demand for these types of behavior, however, it is not as accurate as newer methods [6]. One of the earlier works focusing exclusively on this topic was [6], the Croston's method (CR) was the first to separate the demand size from the demand occurrence. Later it was shown by [7] that this method was biased. [8] proposed a revision to the CR method to approximately correct this bias, the method is known as Syntetos-Boylan Approximation (SBA). However, these methods do not account for the item's obsolescence. To solve this problem, [9] proposed a method that is updated every period, known as TBS (Teunter-Syntetos-Babai) method.

The Machine Learning (ML) techniques are one of the promising alternatives to predict the demand behaviors [10]–[13]. These technique can identify nonlinear functions from the data sample without any assumptions about its probabilistic distribution, making them good candidates for forecasting methods [11]. [10] proposed radial and elliptical basis functions networks to forecast the demand with inputs. [11]–[13] adopted multilayer perceptron networks (MLP) as the forecasting method. However, these methods only considered the pattern of the demand and not the cause of the behavior.

In this paper we go further and model a multi-layer perceptron neural network with internal knowledge of the process that drives the demand. For this, the artificial neural network (ANN) was implemented on data from the indirect material replenishment process of a helicopter engine maintenance company. The dataset is composed of 19 items with different characteristics. To compare the results of the proposed NN, the following traditional methods were employed: moving average, SES, CR, SBA, and TSB. In addition, the networks from [11]–[13] were implemented. The results were compared using three different performance measures and to ensure a robust validation of the results, a statistical analysis was performed.

This work is organized as follows: Section 1 introduces a literature review of the aforementioned forecasting methods and; in Section 2, it is presented the methodology followed in this paper; Section 3 contains the forecast results and the statistical analyses performed on the results; Section 4 presents the conclusions and future works.

1. Demand forecasting methods

Forecasting the demand is an essential element in any inventory control. Furthermore, it is a difficult challenge when the demand in intermittent or lumpy [13]. The single exponential smoothing method is commonly used in the industry and it is considered the standard method for intermittent demand. However, it has a bias associated with it, because it sets the last demand data with the highest weight. Therefore, the forecast tends to be higher after a demand occurrence, and lower before one [6].

To minimize this bias, [6] proposed a forecasting method composed of two SES, one for the demand size and one for the interval between non-zero demands. The CR method only updates the estimations when there is a demand occurrence. Nevertheless, this method was also proved to be biased [7]. To overcome this bias, [8] proposed a correction to CR method, making it an approximately unbiased demand estimator. This method is known as Syntetos-Boylan Approximation. [8] showed the superiority of the SBA method over the CR method in an experiment of 3000 stock-keeping units in the automotive industry.

As the CR and SBA methods are only updated when there is a non-zero demand occurrence, the predictions can become inaccurate after several periods with zero demand. This happens when an item is at risk of obsolescence. This results in a positive bias in the prediction. To solve this bias, [9] developed a forecasting method, TBS, that uses the demand probability and not the demand interval, therefore, it is updated every period. For the demand size, it utilizes the same formula as the CR and SBA methods.

Apart from the traditional methods, there are forecasting methods based on machine learning techniques, specifically, artificial neural networks. ANNs are regarded as been able to provide good approximations to most functional relationships. And by adding more attributes to the model, the prediction results can be improved [11]. ANN can also model non-linear relations in the data, commonly present in the intermittent demand behavior. This non-linearity can be overlooked by most traditional methods. In addition, for the implementation of the ANNs, there is no need for any statistical distribution assumptions [10]. Altogether, the ANNs have great potential for forecasting the intermittent behavior of the demand [11].

To the best of our knowledge, the first work focusing on predicting intermittent or lumpy demand using ANNs was [10]. They utilized three different basis functions networks for predicting the demand. The networks were Gaussian radial basis function (RBF), normalized Gaussian radial basis function (NRBF), and Gaussian elliptical basis function (EBF). The number of inputs and basis functions in the hidden unit layer was optimized for each time series. They implemented two different types of prediction. The first one was forecasting the future total demand for a period; and the second type, they forecasted the demand size and the time of the next demand occurrence. Their results showed that RBF was better suited for predicting the intermittent demand compared to the other ANNs, and it had a better performance than the CR method.

[11] proposed a MLP network trained by back-propagation to predict the future demand size for the next period. The ANN had three layers, one input layer, one hidden layer, and one output layer. The input was composed of the past demand and the number of periods between the last two non-zero demands. The hidden layer was composed of three neurons, enough to approximate most complex functions [12]. They compared their ANN to the traditional methods SES, CR, and SBA. Their results indicated that their ANN was, generally, superior to the other methods. One downside of neural network is the fact that it utilizes one dataset for training and one for testing, so it is not continuously updated with new information, while the traditional methods are updated each period.

[12] adopted the same network configuration as [11], but it changed the input layer. They used as input the number of consecutive zero-demand periods instead of the number of periods between the last two non-zero demands. For comparison, traditional methods (SES, CR, SBA, and weighted moving averages) were also implemented. Their ANN had the best overall performance in the dataset compared to the traditional methods.

However, [11], [12] did not compare their networks with other networks. [13] filled this void by comparing their proposed ANN, the two networks mentioned and the traditional methods CR and SBA. Their ANN combined the inputs from [11], [12] having three inputs. In their work, they tested different configurations of networks, including the network architecture, the learning approach, and the learning method. They tested three types of network architecture: feedforward neural networks, time-delay neural networks, and recurrent neural networks. For the learning approach, they tested two types: back-propagation and extreme learning machines. They assessed two different types of learning modes: batch and online. We recommend seeing [13] for further information on the configurations. Their results showed that the ANNs had a significantly better performance compared to the traditional methods. Also, the ANNs trained with the back-propagation had better performance than the ones trained by the extreme learning. And considering the training with back-propagation, the ANN from [12] achieved better results in some metrics.

2. Methodology

The objective of this paper is to model a multi-layer perceptron neural network to predict the demand behaviors based on the internal knowledge of the process that drives the demand.

To evaluate the performance of the proposed MLP, it was compared to traditional methods and known ANNs. The selected traditional methods were: (i) Moving average; (ii) Single exponential smoothing; (iii) Croston's method; (iv) Syntetos-Boylan Approximation; (v) Teunter-Syntetos-Babai method. The ANNs selected are from [11]–[13]. Table 1 presents all the methods compared in this work, their compact notation, and their parameters.

Table 1. Forecasting methods, their notation, and parameters.

Method	Notation	Parameters
Moving average	MAX_Y	X indicates the number of weeks considered for the average and Y indicates the updating frequency in weeks
Single exponential smoothing	SES	One smoothing constant
Croston's method	CR	Two smoothing constants
Syntetos-Boylan approximation	SBA	Two smoothing constants
Teunter-Syntetos-Babai method	TSB	Two smoothing constants
ANN from [11]	GUTI	Number of hidden layers, number of hidden neurons, learning rate, momentum factor
ANN from [12]	MUKH	Number of hidden layers, number of hidden neurons, learning rate, momentum factor
ANN from [13]	LOLL	Number of hidden layers, number of hidden neurons, learning rate, momentum factor
Proposed ANN	CREP	Number of hidden layers, number of hidden neurons, learning rate, momentum factor

These methods are implemented in a dataset of 19 weekly time series company with 345 datapoints each from a helicopter engine MRO.

The methods' performances are analyzed based on three accuracy measures: MAPE (Mean Absolute Percentage Error), MPE (Mean Percentage Error) and PB (Percentage Best). The combined analysis of the three measures gives an overall perspective of the method's behavior.

To enable the comparison of the methods, statistical analyses are performed on the results of the three accuracy measures, MAPE, MPE, and PB. The first one is the rANOVA to identify if there is one method significantly different from the others. The rANOVA was chosen over the ANOVA since all the methods are evaluated on the same sample. If the rANOVA indicates that there is a difference in the methods, a pairwise paired t-test is conducted. This test can identify if two methods as significantly different from each other. The statistical significance level utilized for both analyses is 0.05.

The following subsections discuss in more detail the data utilized in the project, the ANN proposed the setting of each methods' parameters and the accuracy measures.

2.1. Data

The modeled ANN employs an actual demand dataset from a helicopter engine maintenance company based on Rio de Janeiro, Brazil. The dataset is composed of 19 weekly demand time series with 345 observations each. To understand the demand behavior of the dataset, the squared coefficient of variation of demand (CV^2) and the average inter-demand interval (ADI) was computed. These two variables indicate the demand size erraticness and the intermittency of the demand occurrence, respectively. Based on [4], these two variables are used to categorize the behavior as erratic, smooth, intermittent, or lumpy. The threshold values for the categorization ($CV^2 = 0.49$ and ADI = 1.32) were derived from a theoretical comparison of the performance of the SES, CR and SBA methods over constant lead time. Figure 1 plots the scattering of the 19 time series CV^2 and ADI from the dataset, it also shows the threshold values for the different demand behaviors. As seen in Figure 1, most items have an intermittent behavior (9 items) or lumpy behavior (8 items). Smooth and erratic behavior correspond to 1 item each in the dataset. Therefore, the methods focusing on the intermittency of the demand are suitable for the provided data.

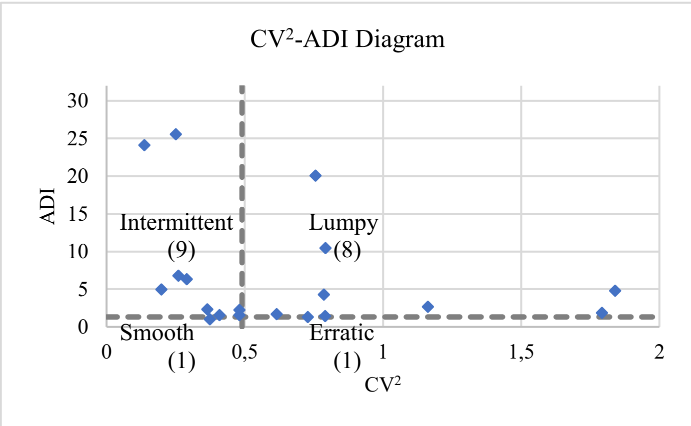

Figure 1. CV^2-ADI categorization diagram.

2.2. Proposed network

In this paper, a neural network with specialized knowledge is implemented. It is a multi-layered perceptron trained by a back-propagation algorithm. Following the guidelines proposed by [14] for multi-layered perceptron, the network is composed of three layers: (i) one input layer with 50 neurons; (ii) one hidden unit layer with three neurons; and (iii) on output unit layer.

Specialized knowledge is utilized in the input layer. This knowledge is composed of information that might impact the behavior of the demand specific to the company analyzed. The variables considered are: (i) year; (ii) trimester; (iii) month; (iv) engine input; (v) engine output; (vi) number of zero-demand occurrence in sequence; (vii) the number of periods between the last two non-zero demands; and (viii) the last demand. All these variables are input neurons for the first layer. In addition, the historical information of the last 4 datapoints of the variables (iv) to (viii) is also used as input. This conveys the sense of production history to the ANN. The variables (vi) and (vii) were presented by [12] and [11], respectively.

The identification of the variables was achieved by expert interviews from different areas related to production. These areas include production planning and control, inventory managing, and manufacturing.

The settings for the ANN were one hidden layer with three hidden neurons, a learning rate of 0.01, a momentum of 0.01, and 30,000 epochs. It was trained by a back-propagation algorithm.

The output unit layer represents the demand value of the next period and it is connected to all hidden neurons.

2.3. Parameter settings

The traditional methods SES, CR, SBA, and TBS have smoothing constants that need to be defined. Based on the recommendations from [6], [15] to choose the parameters in the range of 0.05 to 0.20, we opted to use 0.1 for all the constants. For the moving average, it was decided to use the configuration MA52_26, the mean of the former 52 weeks updated every 26 weeks. The ANNs followed the same configuration as the proposed network.

Each of 19 time series was partitioned into two datasets, one for training (65%) and one for validation (35%), as used by [12]. The division was based on the chronology of the samples, the older datapoints were used for training and the newer ones for validation. This way, the traditional methods can be calibrated before they are utilized, and the ANNs can be trained and their parameters settled using the same dataset. The forecast results from the validation dataset were used to assess the methods' performance. One important distinction between traditional and ANNs methods is that the first is continuously updated and the second is not.

2.4. Accuracy measures

Different accuracy measures provide different insights about the error of the predictions. Therefore, to use only one measure would not give a complete understanding of the prediction methods [16]. We opted to use only non-scale dependent measures, so the statistical analyses on these measures would be possible [17].

The first accuracy measure utilized is the MAPE, it is the most adopted non-scale measure [12]. This measure provides insides of the bias magnitude. The standard definition of the measure uses the ratio $|E_t|/y_t$, where E_t and y_t are the error and the actual demand in period t, respectively. Since there are zero demand occurrences, the following modified equation is used:

$$MAPE = \frac{\sum_{t=1}^{n} |\hat{y}_t - y_t|}{\sum_{t=1}^{n} y_t} \tag{1}$$

The second accuracy measure is the MPE, the ratio of the mean error and the average demand. It indicates the overall bias behavior of the error, in other words, it indicates if the method underestimates or overestimates the prediction. The equation of MPE is as follows:

$$MPE = \frac{\sum_{t=1}^{n}(\hat{y}_t - y_t)}{\sum_{t=1}^{n} y_t} \quad (2)$$

The last measure is the Percentage Best which is the percentage of times one method outperforms the rest considering one specific criterion, in this case, we utilized the absolute error.

3. Results and discussions

The means and variances of the accuracy measures for each method are presented in Table 2. For a more comprehensive analysis, this section is divided by each accuracy measure.

Table 2. Accuracy measure mean and variance for the forecasting methods.

Measure	MA52_26	SES	CR	SBA	TBS	MUKH	GUTI	LOLL	CREP
MAPE Mean	1.281	1.277	1.291	1.268	1.272	1.151	1.151	1.152	1.177
MAPE Variance	0.363	0.254	0.445	0.410	0.268	0.195	0.193	0.197	0.258
MPE Mean	-0.044	-0.006	0.015	-0.035	-0.004	-0.195	-0.196	-0.195	-0.161
MPE Variance	0.111	0.017	0.158	0.142	0.024	0.077	0.074	0.078	0.094
PB Mean	0.217	0.130	0.025	0.072	0.076	0.064	0.138	0.129	0.149
PB Variance	0.030	0.012	0.001	0.008	0.002	0.009	0.027	0.007	0.023

3.1. MAPE

From the information of Table 2, it can be ANNs have, generally, a lower MAPE mean than the traditional methods, meaning that their absolute bias is lower. And, the MAPE variance of the ANNs tends to be lower than the other methods.

The rANOVA (Table 3) indicates that at least one of the methods is significantly different from the other (p-value = 0.002 < 0.05). The rANOVA also indicates that the time series is also significant for the MAPE result.

Table 3. rANOVA for MAPE.

Source	SS	df	MS	F	p-value	F crit (0.05)
Time Serie	43.010	18	2.389	98.211	2.149E-71	1.676
Method	0.624	8	0.078	3.204	0.002	2.003
Error	3.504	144	0.024			
Total	47.140	170				

To identify the different methods, a pairwise paired t-test is conducted, and its result is presented in Table 4. It can be seen that the SES is statistically inferior to all the ANNs implemented, but it is not significantly different from the other traditional methods. The known conclusion that SBA is less biased than the CR method is validated once more.

Also, the ANN proposed in this paper is the only network statistically less absolute-biased than the CR method. In contrast, the proposed ANN is the only network not different from the TBS method. There is not a significant difference between the ANNs considering the MAPE.

Table 4. Significantly different paired methods for the measures of accuracy MAPE, MPE, and PB.

MAPE		MPE		PB	
SES	MUKH	SES	MUKH	MA52_26	CR
SES	GUTI	SES	GUTI	MA52_26	SBA
SES	LOLL	SES	LOLL	MA52_26	TBS
SES	CREP	SES	CREP	MA52_26	MUKH
CR	SBA	CR	SBA	SES	CR
CR	CREP	CR	MUKH	CR	SBA
TBS	MUKH	CR	GUTI	CR	TBS
TBS	GUTI	CR	LOLL	CR	GUTI
TBS	LOLL	CR	CREP	CR	LOLL
		SBA	CREP	CR	CREP
		TBS	MUKH	TBS	LOLL
		TBS	GUTI	MUKH	LOLL
		TBS	LOLL	MUKH	CREP
		TBS	CREP		

3.2. *MPE*

In general, the traditional methods have a better performance than the ANNs considering the MPE accuracy measure. The traditional methods resulted in MPEs closer to zero, with an overall MPE mean of -0.0147, and the ANNs tend to underestimate the demand size, with an overall MPE mean of -0.187.

The results from the rANOVA imply that the forecasting method and the item significantly impact the MPE of the prediction. Table 5 shows the results from the rANOVA. Moreover, the results of the t-tests in Table 4 show the paired methods that can be considered significantly different. The traditional methods SES, CR, and TBS have a smaller bias compared to all ANNs. Also, the CREP network and the SBA method are significantly different from each other. Between the ANNs, the CREP network had the closest value to zero, meaning, it had the smallest bias, however, the t-test did not indicate a significant difference between neural networks.

Table 5. rANOVA for MPE.

Source	SS	df	MS	F	p-value	F crit (0.05)
Time Serie	5.668	18	0.315	5.469	1.304E-09	1.676
Method	1.314	8	0.164	2.852	0.006	2.003
Error	8.292	144	0.058			
Total	15.274	170				

3.3. *PB*

While the previous accuracy measures indicate how much each method is different from the others, the percentage best expresses how many times one method is better than the others. From Table 2, the method with highest mean PB is the moving average, followed by the CREP network.

The rANOVA for this measure indicated that the method has a significantly impact on the forecast result, as seen in Table 6. And, as expected, the time series have no impact on the measure, because the sum the measures across the time series is approximately 1.

The pairwise paired t-test results (Table 4) indicate that the moving average is superior to the other traditional methods (except for SES) and to the MUKH network. The CR method have an inferior performance when compared to most other methods. The PB was the only accuracy measure to indicate a significantly difference between the ANNs, the CREP and LOLL networks have significantly better results than the MUKH network.

Table 6. rANOVA for MPE.

Source	SS	df	MS	F	p-value	F crit (0.05)
Time Serie	1.404E-31	18	7.800E-33	5.308	1	1.676
Method	0.502	8	0.063	4.269	0.0001	2.003
Error	2.116	144	0.015			
Total	2.619	170				

4. Conclusion and future works

To have a truly integrated smart production factory, it needs to have a transdisciplinary development. This process involves different areas from the company and will impact the way the enterprise functions. Therefore, it should integrate various expertise and it should be composed of small steps. This paper proposed an artificial neural network with specialized knowledge for forecasting intermittent demand. To the best of our knowledge, this is the first work to implement an ANN focusing on intermittent behavior with inside information on the production.

Considering the MAPE as the accuracy measure, the CREP network has a better overall performance than the traditional methods. Even though the MPE is smaller than the other ANNs, it was not able to differentiate them by the statistical means. The MPE indicates that the traditional methods have mean error closer to zero than the ANNs, and that the ANNs have a propensity to underestimate the forecast. The CREP network was the best demand predictor multiple times, having the second highest PB. A surprising result is that the moving average had a great performance. It had the highest value for PB and was not significantly different from the best methods in the other accuracy measures. Based on these results, it can be concluded that the use of ANNs and relevant attributes identified by experts have a great potential as a forecasting method for intermittent demand.

This paper did not optimize the parameters for each method, therefore, there are possibilities to improve the forecasting results furthermore. Not only the smoothing parameters for traditional methods but different network configurations for the ANNs. This way, a comparison of these methods optimized will give an insight to their possibilities.

Another possibility to improve the forecasting is to combine different forecasting methods to create hybrid models. This way, we can unite the best characteristics of each method and minimize their disadvantages.

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Intelligent Identification of Trademark Case Precedents Using Semantic Ontology

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Abstract. A registered trademark distinctively identifies a company, its products or services. A trademark (TM) is a type of intellectual property (IP) which is protected by the laws in the country where the trademark is officially registered. TM owners may take legal action when their IP rights are infringed upon. TM legal cases have grown in pace with the increasing number of TMs registered globally. In this paper, an intelligent recommender system automatically identifies similar TM case precedents for any given target case to support IP legal research. This study constructs the semantic network representing the TM legal scope and terminologies. A system is built to identify similar cases based on the machine-readable, frame-based knowledge representations of the judgments/documents. In this research, 4,835 US TM legal cases litigated in the US district and federal courts are collected as the experimental dataset. The computer-assisted system is constructed to extract critical features based on the ontology schema. The recommender will identify similar prior cases according to the values of their features embedded in these legal documents which include the case facts, issues under disputes, judgment holdings, and applicable rules and laws. Term frequency-inverse document frequency is used for text mining to discover the critical features of the litigated cases. Soft clustering algorithm, e.g., Latent Dirichlet Allocation, is applied to generate topics and the cases belonging to these topics. Thus, similar cases under each topic are identified for references. Through the analysis of the similarity between the cases based on the TM legal semantic analysis, the intelligent recommender provides precedents to support TM legal action and strategic planning.

Keywords. Text mining, trademark infringement, semantic analysis, knowledge ontology, Latent Drichlet Allocation

Introduction

Legal firms and researchers are increasingly studying methods to improve the efficiency of monitoring and protecting the intellectual property of clients. Dabass et al. (2018) discussed the current application of AI in law. Many AI technologies have been applied in fields such as document search and retrieval and intellectual property valuation and forecasting. Surden (2014) described the problems legal practitioners face when machine learning is used to support legal decisions and provide guidelines for developing future applications.

Intellectual property (IP) covers the domain of intangible property which is created by human intelligence, such as trademarks (TM), copyrights, designs, and patents. A TM

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represents a company's distinct image in the market (e.g., name and/or logo of a corporation and its product or service offerred), and shows the brand value of the business. TM owners increasingly aware of TM infringement occurred and take actions to protect their IP rights. TM infringement indicates the unauthorized use of a TM or service mark in a manner that is likely to cause confusion, deception, or mistake about the source of the goods or services. Considering the rising problems of IP issues for online e-commerce settings, TM legal cases occured very often and finding case precedents becomes critical for quick and accurate actions. Nonetheless, manually searching and idetifying case precedents are time-consuming and laborious since each case can be as long as 30 to more than 100 pages. This research establishes a recommendation system for TM infringement cases. The system is based on the construction of a TM litigation ontology. Using text mining methods, features are extracted from cases to build a database which reduces case search time and increases efficiency.

The objective is to develop an intelligent decision support for identifying TM litigation precedents. In this study, US TM litigation cases were collected from the Westlaw database as the machine-readable e-documents. The system provides users (such as lawyers) with an effective tools for searching and preparing litigation. To develop an intelligent method suitable for the precedent recommendation, an intellectual ontology in the field of trademark court judgment is constructed to represent machine-readable trademark infringement legal documents. The system identifies similar precedent characteristics by writing a legal case summary including facts, issues, rationale, holdings and rules (applicable law and cited precedents). Given the connection between the applicable law and the cited case, topics are identified based on the facts and issues from the judgment cases.

1. Literature Review

In this section, literature related to the research domain are reviewed. First, trademark and US trademark litigaiton are breifly discussed and introduced. Then, the meaning of e-discovery and its application is reviewed. Finally, the concept of ontology is introduced.

1.1. Trademark and Trademark Litigation

TMs are constructed using words, phrases, symbols, designs, colors, product or packaging appearance, sounds, or a combination of these elements. The U.S. Patent and Trademark Office (USPTO) defines a trademark as a "word, phrase, symbol, or design, or a combination thereof" that used to identify and distinguish a company's goods. The main function is to identify the source of the goods or services and to distinguish it from that of others. Since a trademark is used as a mark to represent goods or services, the mark must be uniquely identifiable with symbolic features for differentiation that do not confuse or mislead the customer.

In the age of digitalization, trademarks are spread through the social media and have economic and social value protected by law if they mark is registered. In terms of the purpose of trademark legislation, there are two points related to customer and trademark owners respectively. One is to protect the public interest so that customer can be confident when purchasing a product marked with a familiar trademark which ensures the quality and manufacturer of the product. Secondly, since the owner of a trademark has spent time and money developing the brand equity of the marked products and services, there is protection granted law to prevent the counterfeit of goods or infringement of the brand (Rogers, 1949).

The US judicial system is a two-track system, including a state court system and a federal court system. The Federal judiciary of the United States includes the Federal District Court, the Federal Circuit Court or United States Courts of Appeals, and the US Supreme Court. In the US, there are no specialized courts for trademark enforcement. The protection of US trademarks is examined under federal law, state law, and common law. It also adopts a two-track system, a trademark allegation can be brought to federal or district courts. For the federal level of litigations, it applies the federal trademark law; while the state level applies state law for each state and the common law of the unfair competition (Common Law of Unfair Competition).

1.2. E-Discovery

For US litigation, especially civil litigation, the parties involved have the obligation to provide each other with evidence related to issues and facts before the trial, which is called "discovery" (Roitblat et al., 2010; Oard, 2013). According to Conrad (2010), EDD, Electronic Data Discovery or E-Discovery, refers to a process of searching, identifying, processing, and organizing electronic legal information as a critical evidence in the litigation. As the volume of electronic legal documents continues to grow, it takes more time and costs for attorneys to affordably manage this obligation in time. As a result, attorneys are looking for efficient ways to reduce the time for e-discovery without increasing error.

Many e-discovery technologies have been developed for searching electronic evidence such as email, databases, and video files. Many applications use artificial intelligence (AI) to screen large amounts of evidence and performance improves as the applications learn as they search more data over time. For the conventional process of discovery, attorneys manually review and filter relevant evidence for litigation. New technologies have been applied to assist in searching and reviewing relevant documents. The growing volume of electric information drives the demand for technology-assisted review, such as keywords search and predictive coding (Belt, 2011). Endo (2018) reported that machine learning has been successfully used for legal decision making. Application of data collection and data processing of legal documents lowers costs when searching for and analysing the documents and cases. Technology-assisted review is trained by legal experts to recognize and create categories for the input documents. Calo (2016) discusses the use of a robot as a metaphor for assisting a judge during trial litigation.

People can apply the technical process to the analysis of large amounts of legal data. However, without well understanding of the algorithms and the analytic results that the technological system produced, it might cause misinterpretations and more bias. (Conrad, 2010). Some argue that data analytic approaches provide greater convenience rather than the reliability of results. There are increasing concerns that the validity and reasonableness of computational systems, such as machine learning, show different qualities depend on human interpretation. (Endo, 2018; Hildebrandt, 2012). Explicit and implicit biases in the system influence the results and social relevance. According to Burk (2019), algorithmic fair use sholud be considered whether the legal regulations can be translated into the personalized use by machines. Analytic data technologies bring convinces to human, however, it also brings uncertainty due to its simplified assumptions. In order to prevent errors and improper inspection, human-assisted supervision and interpretation are necessary for the automated fair use system. Belt (2011) also concluded that technology-assisted review would be more reliable with proper support from the legal profession knowledge and appropriate process. E-discovery should be a solution for supporting the litigation process and it depends on the understanding and interpretation from the analytic data results.

1.3. Ontology

Ontology originates from a philosophy discipline, which aims to explore the nature of things. According to Gruber (1993), ontology is an explicit form of terminologies representing a domain knowledge (elements and their relations). Studer et al. (1998) defined an ontology as a formal and explicit specification of a shared knowledge conceptualization. In overall, an ontology should represent a knowledge domain comprehensively, which enable machines to communicate and exchange opinions (or understand each other's domain context). Ontology allows domain knowledge to have a common form of representation, enabling computers to achieve true semantic communication. According to Chandrasekaran et al. (1999), ontology schema enables definition, sharing, and reasoning of the representing content. It is not only about the nature and structure of knowledges, ontology can also define the relationships between elements and attributes in a knowledge domain (Staab et al., 2009). Ontology is usually constituted by classes, attributes, instances, and relations. These ontology elements (in nodes) and relations (in arcs), when comprehensively defined, are used to represent a semantic network of domain knowledge.

The ontology schema has been widely used to represent different fields of knowledge. In this research, a TM case judgment ontology schema is defined for developing a TM case precedent recommender using semantic. Recommender systems provide suggested choices based on user's preferences, often shown implicitly in his/her previous behaviors (Shishehchi et al. 2012; Cruz et al. 2015). Munir et al. (2018) introduces and discusses several ontology-based information retrieval approaches in the past research. Trappey et al. (2019) proposed an ontology-based TM litigation case recommender by retrieving case key features defined in TM ontology schema. In this research, we extend the previous research (Trappey et al., 2019) by comprehensively defining frame-based ontology schema for TM litigation knowledge representing approach. The method establishes frame-based feature templates for automatically retrieving features into machine-readable database tables. Machines can automatically generate the information following the framework structure, which can effectively improve recommender's efficiency and reliability.

2. Research Methodology

Figure 1 shows the framework of the intelligent TM precedent recommendation system. There are two modules in the system, i.e., computer assisted knowledge extraction and the identification of precedents based on key legal issues/topics. Users, such as IP attorneys or company's IP counsels, can input a seed case into the system platform. In this research, we collected US trademark litigation judges from Westlaw.com during 1995 and 2018 as experimental data/cases. The input cases will be represented in ontology-based knowledge features, e.g., facts, issues, and rules in the litigation cases. As for the issue identification, the issues are defined by several key terms respectively. LDA topic modeling (i.e., a soft clustering) is, then, applied to find the cases with similar features for precedent recommendation. Finally, related laws, cites and cases are ranked as a prioritized recommended list for users.

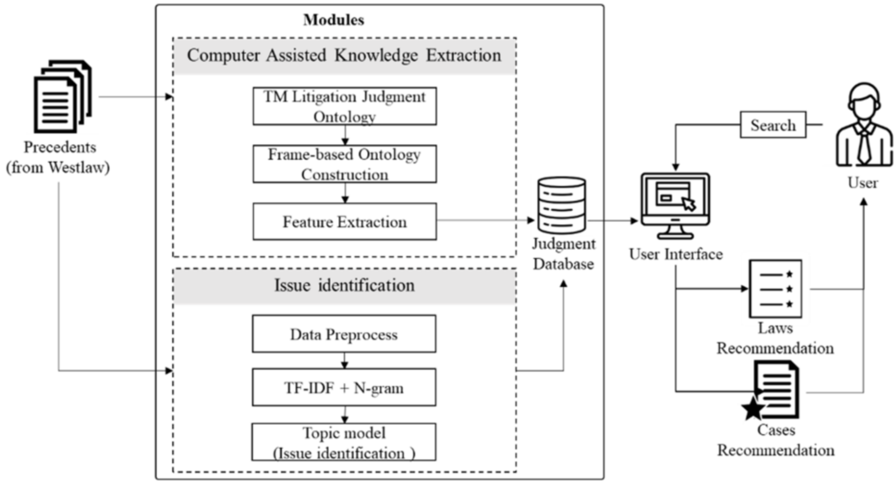

Figure 1. The framework of intelligent TM precedent recommendation system.

2.1. TM Litigation Judgment Ontology

An ontology schema of TM litigation issues is constructed in three levels of classes and their associating attributes. As the purpose of this research is to construct a computer assisted system for recommending relevant cases automatically, the key task is first to convert the judgments (documents) as machine readable data tables. The ontology schema of TM case law is defined according to the essential elements of case brief in common law system. A case brief consists of five essential categories (classes) of case information, including (1) basic data, (2) facts, (3) issues, (4) holdings, and (5) rules (i.e., relevant laws). The ontology schema is further defined into sub-levels of feature classes and their key terms of attributes (as shown in Fig. 2 – sub-classes of "issues" class and their key attributes).

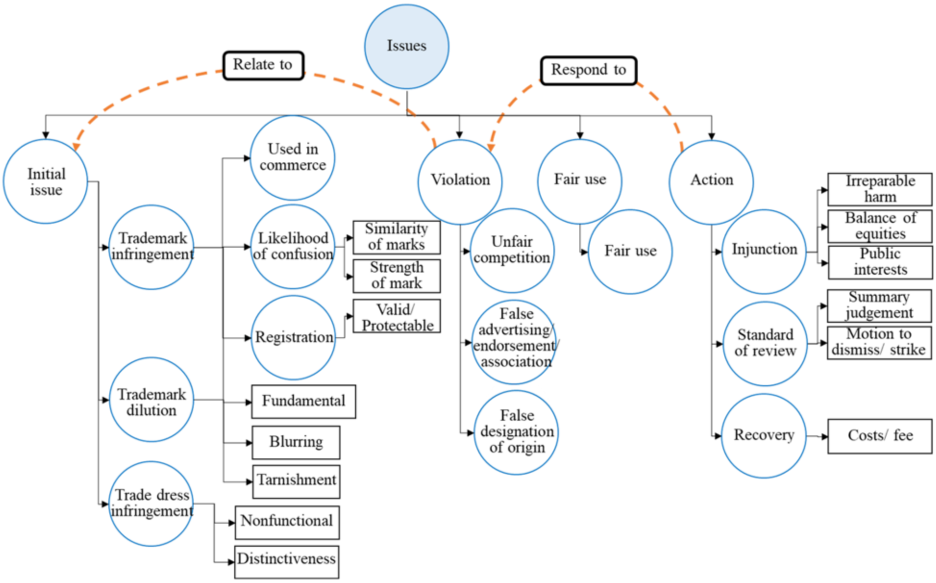

Figure 2. The definition of "issues" class for TM litigation ontology schema.

2.2. Feature Extraction Using Regular Expression

In order to make the system extracting each case judgment's features (or instance values), based on the frame-based ontology schema, there are a standard steps of feature extraction from the litigation judgment. First, to extract the information in the "basic data" class, the regular expression technique is applied according to basic data's legal expression formats (Kleene, 1951). A regular expression is a standard string complying with the required pattern/format of given formal documents and the retrieval of targeted data with regular expression in text corpus is popularly applied in information retrieval practices (Friedl, 2006; Wheeler, 2016). In legal judgments, the laws are written in a certain formats/patterns. Thus, the regular expression can extract the features automatically in large number of documents in the legal corpus.

2.3. Issue Identification

Apart from the other classes of ontology schema, the features of "issues" attributes are retrieved using term frequency–inverse document frequency (TF-IDF) and N-gram algorithms for identifying frequently appeared and highly representative key words and phrases (collectively called *key terms*) (Qaiser, 2018, Robertson, 2004). According to TM litigation ontology schema, as shown in Fig. 2, the main issues and relevant key terms are defined. The TF-IDF and N-gram key-term retrieval for any given judgment can assist the recognition of the case features and identify the most related issues of the given case. Additionally, Latent Dirichlet Allocation (LDA) is further deployed for soft clustering cases into topic models (Blei, 2003). Both identifications of issues and topics of TM cases in the corpus will support the findings of case law precedents for any given seed case. In the research, judgment documents of US TM litigation cases require pre-processed through tokenization, stop words cleaning, and lemmatization prior TF-IDF, N-gram, and LDA test mining operations.

2.4. Judgment Database

After the steps of computer assisted knowledge extraction and issue identification, we then build a database for storing and linking the key features of each case in formatted data tables for the cases (their features) similarity comparison. In the database, issues will also be linked to the most related federal laws. When users input seed cases to the system, the system will display relevant precedents (with similar issue attributes) and highlight the relevant federal laws.

3. Trademark Judgement Discovery

Based on the TM litigation ontology constructed in Section 2, all TM litigation cases in the case corpus are automatically converted to frame-based, machine-readable knowledge representations. With the use of the system, critical features or values of instances and attributes (under 5 main classes of ontology schema) are retrieved and compared for discovering most relevant precedents. In order to verifying the system at work, fifty TM cases are randomly selected to test the case judgment recommender results. In our research, US TM litigation judgments from 1995 to 2018 are collected in the legal corpus using the search key-term "trademark infringement." We have found more than 4,800 TM infringement cases litigated in the US district and federal courts (1995~2018). Fifty cases are randomly selected as experimental judgments. The key features of these 50 judgments are retrieved for identifying similar case precedents.

3.1. Identify Precedents in Matching Issues and Their Key Terms

To identify precedents by relevant issues, issue key terms are defined and recognized before feature extraction. Table 1 lists ten TM litigation issues' key terms, their applicable rules, and the case examples. The relevant key terms are defined according to the attributes in the proposed TM ontology's "Issues" schema (in Fig. 2). The cases with frequently appeared terms, matching the key terms of specific issue(s) are listed in the last column of Table 1. The precedents, belonging to the same issue(s) of the seed case, are identified and ranked based on the matching key terms' frequencies. The system would finally identify and display the related precedents according to the related litigating issues. In addition, applicable rules are recommended according to the corresponding issues (as shown in the third column of Table 1).

Table 1. Issue key terms, applicable rules, and matching cases.

Issue	Key terms	Rules (Law)	Cases IDs
Trademark infringement	Trademark infringement, confusion, likelihood of confusion, consumer confusion, strength, similarity, valid, validity, protect, protectability, registration, Polaroid Factors	15 U.S.C. § 1114 15 U.S.C. § 1125 15 U.S.C. § 1051 15 U.S.C. § 1115(a)	All the cases
Trademark dilution	Dilution, diluted, distinctive, blurring, tarnishment, distinctiveness, famous, similarity, in commerce, recognition, actual association, secondary meaning	15 U.S.C. § 1125(a) 15 U.S.C. § 1125(c)	8, 13, 17, 20, 45
Trade dress infringement	**Trade dress infringement, trade dress, nonfunctional, distinctive, appearance, design, shape, strength, similarity**	**15 U.S.C. § 1125(a)**	**5, 12, 18, 28, 44**

Unfair competition	Unfair competition, deceptive trade practice, deceptive trade, bad faith, fraud, imitating, counterfeiting,	15 U.S.C. § 1125(a)	16, 19, 20, 27, 44
False designation of origin	False designation of origin, country of origin, false, mislead	15 U.S.C. § 1125(c)	13, 20, 26, 30, 34
False advertising/ endorsement/ association	False advertising, false endorsement, false association	15 U.S.C. § 1125(a)	13, 19, 30, 32, 41
Fair use	Fair use, fair use doctrine, good faith, affirmative defense, Nominative use, descriptive use	15 U.S.C. § 1115(b)	25, 29, 33, 40, 48, 50
Injunction	Irreparable harm, equities, balance of equities, public interest, preliminary injunction, permeant injunction, Injunctive relief	15 U.S.C. § 1116 15 U.S.C. § 1125(c) 15 U.S.C. § 1127	1, 14, 19, 24, 42
Standard of review	Summary judgement, motion to dismiss, dismiss	Lanham act is not applicable.	13, 14, 16, 20, 31
Recovery	Costs, fee, recover, remedies, profit, attorney fee, damages	15 U.S.C. § 1114 15 U.S.C. § 1117(a)	16, 21, 22, 27, 35

3.2. Identify Precedents in Maching Topic Models

LDA topic modeling is applied to identify the implicit semantic topics in the TM litigation cases. In order to ensure high coherent level of topic modeling result, Cv coherence score (Röder, 2015) is calculated to measure the topic coherence and performance. Cv measures the quality of topic model using normalized pointwise mutual information (NPMI) and the cosines similarity. A higher Cv score indicates better generalization performance. In our research experiment, total eight topics are generated using 4800 TM litigation cases as training dataset. Table 2 shows all topics' top frequently appeared terms, topic interpretation, and cases matching the topics and high-frequent terms. The LDA topics are further linked to the related issues as presented in the ontology schema in Section 2 (Fig. 2). With the trained topic models, the research identifies the dominant relevant issues and cases for precedents recommender. For example, topic 7 is closely related to the trade dress infringement issue. The cases (#5, 12, 18, 28, 44) match well with the feature extraction discovery in Table 1.

The approaches of identifying precedents based on issues' key terms (Sec. 3.1) and semantic topic modeling (Sec. 3.2) serve as valuable cross-validation for a reliable TM case precedent recommendation system. Through the analysis of the cases' similarities on features, dominant issues, and laws, the precedents can be reliably identified with legal insights and recommender's depth under the core structure of TM litigation knowledge.

Table 2. Topic key terms, interpretations, and example cases.

Topic	Key terms	Interpretation	Cases IDs
1	0.005*"descriptive" + 0.005*"strength" + 0.005*"generic" + 0.004*"secondary" + 0.003*"dilution" + 0.003*"brand" + 0.003*"secondary_meaning" + 0.003*"actual_confusion" + 0.002*"confused" + 0.002*"evidence_actual" + 0.002*"logo"	Relevant policies underlying Interpretation and definition of registered marks by the court.	6, 15, 35, 44, 50

2	0.010*"preliminary" + 0.007*"agreement" + 0.005*"irreparable" + 0.005*"preliminary_injunction" + 0.004*"franchise" + 0.003*"injunctive" + 0.003*"irreparable_harm" + 0.002*"license" + 0.002*"ownership" + 0.002*"motion_preliminary"	(Preliminary) injunction is an temporary order which prohibits the parties from doing an act before the final judgment is made.	1, 14, 19, 24, 42
3	0.012*"dilution" + 0.010*"distinctive" + 0.010*"international" + 0.008*"intellectual_property" + 0.007*"famous" + 0.006*"trademark_dilution" + 0.005*"ownership" + 0.003*"dilution_claim" + 0.003*"trade_name"	Regarding the distinctiveness of the famous mark, whether the act of trademark dilution is constituted.	5, 8, 13, 17, 20
4	0.011*"agreement" + 0.010*"contract" + 0.006*"dismiss" + 0.006*"counterclaim" + 0.005*"breach" + 0.004*"motion_dismiss" + 0.004*"amended" + 0.003*"fraud" + 0.003*"interference" + 0.003*"false_advertising" + 0.002*"pleading"	Unfair competition caused by disputes over trademark infringement.	7, 13, 22, 23, 32
5	0.010*"breach" + 0.008*"bad faith" + 0.008*"essential" + 0.008*"false_advertising" + 0.006*"" + 0.004*"essential" + 0.002*"event" + 0.002*"undisputed" + 0.002*"advertisements"	False advertising with bad faith to mislead and confused the trademark representation.	2, 10, 13, 19, 23
6	0.016*"fee" + 0.014*"award" + 0.012*"profit" + 0.008*"attorney_fee" +0.004*"willful" + 0.004*"counterfeit" + 0.004*"statutory" + 0.003*"verdict" + 0.003*"testimony" + 0.003*"appellant" + 0.003*"remedy"	Awards and remedies judgment decision made on the defendants.	15, 16, 19, 21, 27
7	**0.031*"trade_dress" + 0.009*"secondary" + 0.006*"secondary_meaning" + 0.006*"color" + 0.006*"feature" + 0.005*"functional" + 0.004*"packaging" + 0.003*"shape" + 0.003*"functionality" + 0.002*"distinctiveness" + 0.002*"dilution"**	**Trade dress infringement and dilution on the distinctives and strength of product appearance.**	**5, 12, 18, 28, 44**
8	0.020*"vendors" + 0.012*"contributory_trademark" + 0.010*"property" + 0.008*"contributory_liability" + 0.006*"infringing_activity" + 0.004*"merchandise" + 0.004*"contributory"	Contributory trademark infringement that vendors induces another to infringe other's trademark.	16, 21, 22, 38, 45

4. Conclusion

The research aims to develop an intelligent recommendation system for discovering TM case precedents. The system integrates advanced technologies, such as knowledge ontology, regular expression, text mining, and soft clustering LDA algorithms to help users, such as trademark attorneys or relevant TM stakeholders, find the most relevant TM case precedents and provide valuable case insights, such as litigation issues, rules, and laws. The key contribution of the research is that the system combines the TM litigation key-feature extraction and judgment semantic topic recognition modules to cross-validate the discovery of precedents. The system provides the reliable results based on the similarities between legal precedents' issues, topics, and other pre-defined attributes/features. This research expects to offer a broad view of the intelligent legal analytic methodologies with the combined advanced text mining and semantic processing techniques.

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Customized Product Development Supported by Integrated Information

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Abstract. Information systems are key enablers for the integration and reliable management of the product development process. Information systems are the backbone that connects various sub-processes and enables flexible product customization. Fast, robust, and cost-efficient product adaptation is especially important in one-of-a-kind production. This paper presents a transformation of the product development design process for large power transformers into a competitive and smartly supported process. One-of-a-kind production is specific, as each product must be customized, wherefore a robust design process well supported by IT plays a key role in creating a digital twin and the product's final value. Based on a systematic analysis of the sample company, this paper proposes a model for the complete renewal of information systems and of working methodology, where reorganization is demonstrated in an increase of overall effectiveness.

Keywords. Engineering informatics, process integration, product development tools, lean methods, concurrent engineering, one-of-a-kind production, knowledge management

Introduction

Nowadays companies are facing intense and increasing pressure to reduce costs, establish shorter time-to-market, and increase the added value of the products by investing in their development. That pressure has led to the expansion of activities related to the development and improvement of production processes [1]. Highly individual production requires a high degree of flexibility and timely response to customer needs [2]. Accordingly, good information technology (IT) solutions play a key role in the company's operations [3]. The design process in one-of-a-kind production is characterized by the adaptation of a basic design to individual customer's requirements – adaptive design process [4]. The foundation of a robust design process is sufficient IT support, expressed in the absolute control of data related to one-of-a-kind products and the reliable retention of knowledge and experience. All the advantages provided by such information management systems are optimally developed only with a sound combination of knowledge of the working methods, concurrent reorganization of existing work, and specific upgrades, for example, to the expert system. A transdisciplinary approach is needed that considers technical and social aspects for PDP. The PLM system is an integral system of product management throughout its lifecycle. Managing multiple fields of work leads to better results than when managing those fields

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individually [5]. Another important fact is that 80% of a project's cost is generated in its development [6]. Rogalski identifies six key aims of modern IT tools implementation: higher efficiency, shorter time-to-market, clear communication, enhanced design quality, standardized process design and efficient knowledge management [7]. Appropriate solutions are thus hiding in the development of the IT environment (development of an expert system, combining existing software tools, potential introduction of PDM and PLM systems), in the introduction of the universality and uniformity of working procedures [8], in eliminating redundant tasks (making processes lean), and in the introduction of fast, robust, real-time feedback loops to verify the partial and over-all efficiency [9], [10].

Applying IT support and knowledge management is of key importance for more efficient and robust design process [11],[12],[13]. The case of the development and production of large transformers is discussed. The result of many such years of transformation is the toolset of modern information support and knowledge management, which enables a company's competitiveness and further growth. Several supporting tools have been developed that accelerate the robust creation of a product's digital twin. The transformation itself is presented first with all the company-specific details and later in the generalized model. Therefore, the information support model presented here is the main contribution of this publication and it is applicable in most companies that need to tailor their products to individual customers. In parallel with the redesign of information support, organizational changes in the product development process (PDP) were made within the company, and a great effort was made in gaining new employee competencies. Information support is a very important tool, but it cannot replace engineers. A holistic approach is needed that includes advanced computation tools, communications with customers and suppliers, and cultural changes within an enterprise that stimulate the sharing of knowledge and the application of agile and lean methods into PDP.

1. Model for IT support of PDP in One-of-a-Kind Production

The IT support of PDP model is analyzed in the context of a one-of-a kind business environment. The design of each new power transformer is suited to an adaptive type of design. For example, when a new design problem arises, it is solved through the modification of an existing design rather than performing the design process from the beginning. The guidelines for IT support in OKP were drafted (Table 1) based on agile and lean methods, the CE approach, a literature review, the authors' experiences, and a detailed analysis of activities and the information flow. The proposal considers that the information involved in the product development process is complex and comes in several forms (3D models, drawings, calculations, numerical simulation, design parameters, etc.). There are also several creators and users of information in the process chain. Product development must be accelerated by applying different kind of supporting tools. There is a need to ensure a high degree of reliability in the transfer of information between different subsystems, and control mechanisms must be applied. Human involvement in knowledge recording and reuse must be integrated into IT support.

Product knowledge must be integrated into product design tools that enable fast and reliable product configurations according to specific customer needs – creation of a product's digital twin. Such tools can be implemented as a variable bill of materials that specify which building blocks are compulsory and which one are optional. All possible options, product pre-development and design tools are conducted already before the first customer order is confirmed. In the case of more complex products and specific requests the whole product or at least some of the modules need to be designed according to specific requests. In such cases, parametric modelling can be a helpful tool that enables not only faster design, but considers several rules and constraints for better product robustness. The background of such tools is systemic PD that considers modular structure, platform design, adaptive design, and the exchange and interchange of standard building blocks. Product family and tool development must be completed before or in parallel to the running project for customers.

Table 1: Specific requests for IT support in one-of-a-kind production.

IT criteria	Way of implementation
1 Application of PLM system	• User-friendly way for searching similar modules, parts • Independent storing/documentation of modules (ready for reuse; a prerequisite for internal standardization) • Variable bill-of-materials for fast, reliable product configuration
2 Computer supported work at all PD phases Tools and methods for adaptive product design	• Computer-aided parametric product design that enable semi-automatic customer specific product creation • Modular product structure, standardization of building blocks • Product family, platform design
3 PDP is integrated into PLM workflow configuration	• Smooth data transfer inside PDP • Control mechanisms for data transfer between different modules • Integration between different software tools
4 Integration of external teams into information system	• Information connection between manufacturer and sub-suppliers + Long-term strategic relationship
5 Integration of PDP and data with other business processes	• Establish smooth workflow • Integration with ERP
6 Implementation of knowledge management	• Integration of new knowledge into tools and methods for PD (recording of new findings, use of stored knowledge) • The creation of EC propagation maps on each product family • There is systemic knowledge generation; research work parallel to running projects • Research must run in parallel and new findings must be integrated into design tools.

2. A case study: One-of-a-kind production of large power transformers

A manufacturer is a typical representative of a one-of-a kind production. The sample company is a renowned manufacturer of large power transformers. The case study demonstrates how to organize IT support and create tools and methods for adaptive product design, for the creation of a product digital twin. The basic working principles as well as the peripheral functional requirements are known. Every design begins from the same baseline, which is the selection of the appropriate parametric 3D model layout. Parametric models consist of smart subassemblies and parts whose design is well considered and founded in the company's experience and knowledge, along with a number of standard components. Despite well-structured and content-rich parametric constructions, each new individual contract requires the modification of numerous details, which makes each final product unique. The individualization process includes the parametric change of advance prepared components and sometimes a certain degree of completely newly designed components. The human factor at this point is of great importance, as it directly affects the final number of detected or undetected errors. The aim is the elimination of the human factor within the limits of everyday engineering usability and economic viability. The authors of this paper argue that, on the basis of a systematic analysis of a development and design process, it is possible to establish a smart system of information and methodological support to reorganize activities such that they makes the adaptive design process robust, smart, and therefore effective.

Figure 1 summarizes specifics of adaptive design process in one-of-a-kind production. Tools and methods for agile product configuration and adaptive design is a framework that enable a fast and reliable response to customer specific requests. Basic research such as noise reduction runs in parallel to the projects aimed at realizing customer orders. The results of basic research are later integrated into design tools. The structure of IT support and the interconnection of different sources of information is the focus of this paper. It is important to ensure the security and integrity of information during a transfer between different sub-systems. Several tools were thus established for the faster execution of design activities, and for information sharing and reuse.

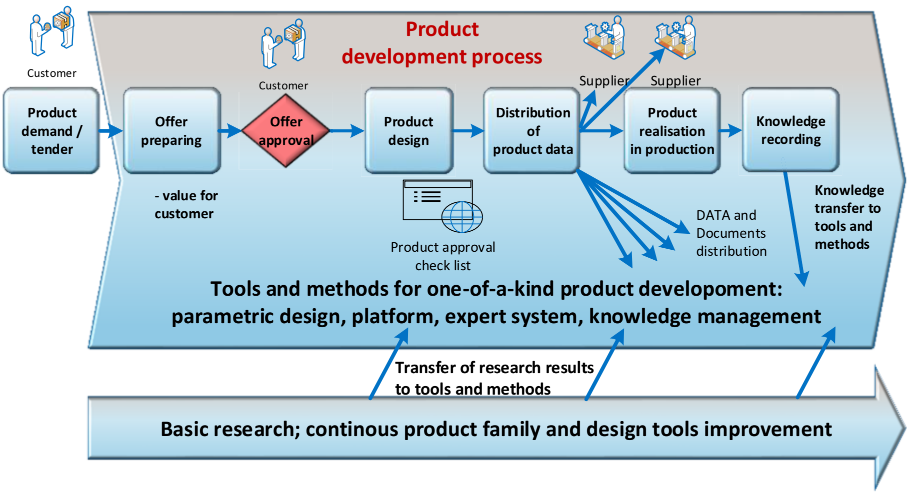

Figure 1. Generalized adaptive design process in one-of-a-kind production of complex products.

This paper's contribution is in the integrated product information model, the description of supporting tools, and the model of integration with the design processes of customized power transformers. The used approach of information management can be generalized and applied to other manufacturing companies. In the following sections specific IT supporting tools are presented: the expert system, parametric modelling, PD computer aided tools, and knowledge management.

3. IT support and computer aided tools for PDP

OKP products are customized solutions which satisfy the customer requirements with a high level of variety. A business strategy based on OKP products requires design tools for the efficient generation of product variants [14]. Usually, the design of OKP solutions such as complex engineering systems (e.g. power transformers) starts from a template configuration. In this context, the appropriate combination of design information that meets technical goals and customer requirements is the main challenge [15]. Albers et al. highlighted how a lack of tools still exists in the development of flexible and agile design methods to support optimized workflows [16].

3.1. Internal standardization, modularity and platforming

The reuse of previous solutions is well known in companies that produce customized and modularized products. Modularity was applied in this context to reusing pre-designed modules efficiently, greatly influencing the fields of adaptability, flexibility, and agility. One-of-a-kind products usually comprise three main groups of components. The core group includes characteristic components that define the product. They are individually adapted to certain project requirements via controlled process re-engineering. This means that any modification is made with special concern, as any changes to those components usually mean almost certain accommodations to adjacent, usually subordinated subsystems. In another group, components suitable for standardization are classified. Those components are usually very important for the agility of the entire process. Although they are usually not of great importance to customers, they simplify the product structure in terms of standardized solutions, especially in detailed design. The challenge is to reduce variation while preserving the creativity that is necessary for the creative process. Standardization enables the creation of highly stable and predictable outcomes with both high quality and precise timing in an unpredictable environment. Examples of standardized parts may include flanges, supports, lifting and lashing lugs, inspection openings, etc. The last group of components contains components suitable for the absorption of changes. Such components are typical for one-of-a-kind production since they increase customer-perceived value. Their numerousness generally dictates a product’s market success.

A modular architecture encourages the development of self-contained and relatively independent (or loosely connected) assemblies or modules that can be detached, modified, relocated, and replaced easily. Because the modules in a modular product are relatively independent, these modules can be designed and manufactured separately. Modular design help in creating a range of products with minor variances and allows some components to be used across product variants and product lines due to standardization of the functions and interfaces.

Product platforming is a specific solution approach that focuses mainly on offering high product variety to customers while reducing development and manufacturing costs. Products sharing the same platform usually form a family of products. Platform design is considered as the extension of modular design by using the platform – the main module – in all the products of this family. In adaptable design, the functions of different products can be achieved using the platform design approach. When certain functions are required, the modules with these functions are then attached to the platform.

Subassemblies of power transformers are designed as scalable platforms with standardized connection interfaces. Changes between different modules can be made with ease, because parameters delivered into the master assembly via expert systems define the geometry on the top level of each platform. Excluding one module and activating another one usually has no serious influence on geometric stability of other adjacent platforms. Modules are attached to the platform with auto placement rules (Fig. 2). Rules are written into the module’s parametric settings using designated coordinate systems, points, axes, or datum planes for navigation. Components that need to be flexible are designed to fully accommodate parametric sketches, which are the foundation of any scalable platform (see the cooling battery pipe frame).

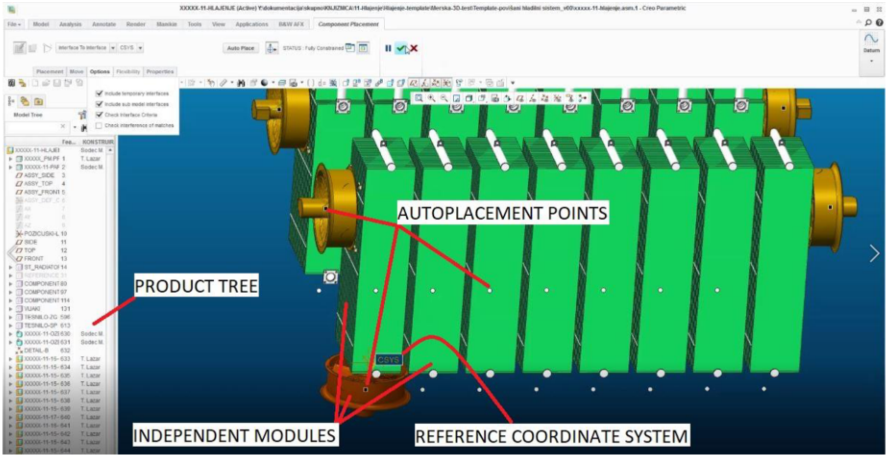

Figure 2. Smart auto placement rules with spatially oriented components enable easy and efficient change, addition, or deletion of components. Basic radiators on the ends of the cooling system were replaced with radiators with fan braces.

3.2. Computer-aided tools for PDP and expert system

The digital twin of complex one-of-a-kind products requires the optimization of advanced solutions where parameters are related to scalable and modular platforms. In this context, the integration between optimization tools and model-based simulations is necessary to manage the complexity. Computer Aided Engineering (CAE) tools are applied to compare the mechanical behavior of different OKP configurations and, therefore, they are involved into optimization loops [17]. In mechanical and electronic applications it is an important challenge to select feasible system architecture that satisfies both technical requirements and customer preferences [18].

Figure 3 presents the methodology framework: the input parameters are fundamental preconditions for preliminary design. In the case study these are electrical calculations about the power transformer, customer requirements, preliminary outline and transport drawing, tender data, equipment bill of material, etc. The general product architecture is defined in the preliminary design phase by selecting an appropriate platform for each product subassembly. Advanced parametric design enables an efficient configuration design process because all platforms are interchangeable due to their unified connecting interfaces. Parametric modularity also enables effective design iterations in the event of late design changes.

The internally developed expert system represents the core of the design activities and helps to manage the development of a product digital twin. It represents a functional link between preliminary design space, the knowledge database, and simulations (Fig. 3). The expert system enables the multilateral exchange of parameters and increases the robustness of the whole operation in the event of any redesign activities. An overview between numerical simulations and input/output parameters enables the chief design engineer to effectively conduct numerous calculations in a short time period. In addition to the basic information distribution it offers to some degree automated decision-making for appropriate design solutions. Expert systems include a database of the import parameters of all main subassemblies that links a structurally finite element analysis (FEM) and later design process in a parametric 3D environment. A comprehensive approach to problem solving that involves intensive simultaneous participation of key members of the project team is essential, in particular electrical and mechanical designers and development engineers. Functional links and progress bars eliminate human errors completely. When introduced, product development and design process made a considerable step towards robust and effective operation. The data field necessary for the realization of the entire activity was reduced by about 50% on both the input and output side. Estimated time savings have been recorded of between 15% and 20%.

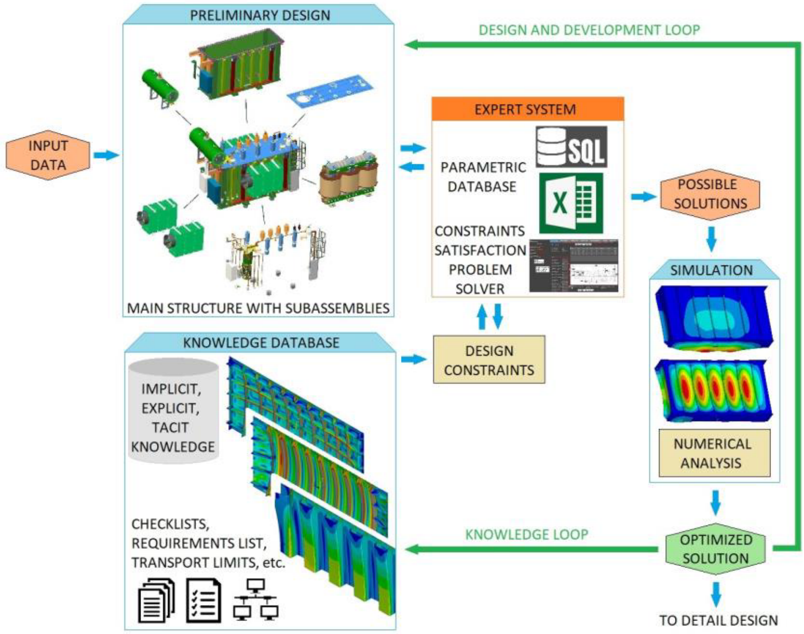

Figure 3. The proposed initial design methodology framework.

3.3. Knowledge management

Proper recording of information should be a part of regular work and not a matter of the engineers' good will at the end of a project. It means that each project, each engineering change (EC) should include the documents, such as design and process FMEA, product history file, and 8D reports with important information. Proper recording of knowledge shall start in PDP, while most knowledge is created during this phase. Recording of new findings needs to continue through the whole exploitation phase of the product life cycle [19]. Customer complaints and new modes of failures from the market are very valuable pieces of information that were not known at the time of PD.

Documents should be available in a central database such as a PLM system and accessible through a user-friendly classification and searching tool. Human-based KM is an acceptable solution for smaller companies with minimal personnel fluctuations. In larger systems with several hundred employees, a systematic recording of knowledge is of utmost importance. Employees must have competencies for systematic work in teams and for recording knowledge in a structured manner; this later becomes a prerequisite for searching. Well-recorded decisions, an explanation of important details, and structured and self-explanatory presentations of data also facilitate the search for and reuse of information for engineers on other teams [13]. An enterprise should foster and promote a culture of knowledge sharing, the permanent recording of knowledge, and its reuse.

Knowledge management consists of five core activities: capture, validation, storage, retrieval, and reuse (Fig. 4). Knowledge stored in documents is used as a resource for better conduct of activities. An organization must enable work in interdisciplinary teams that encourage knowledge creation and sharing.

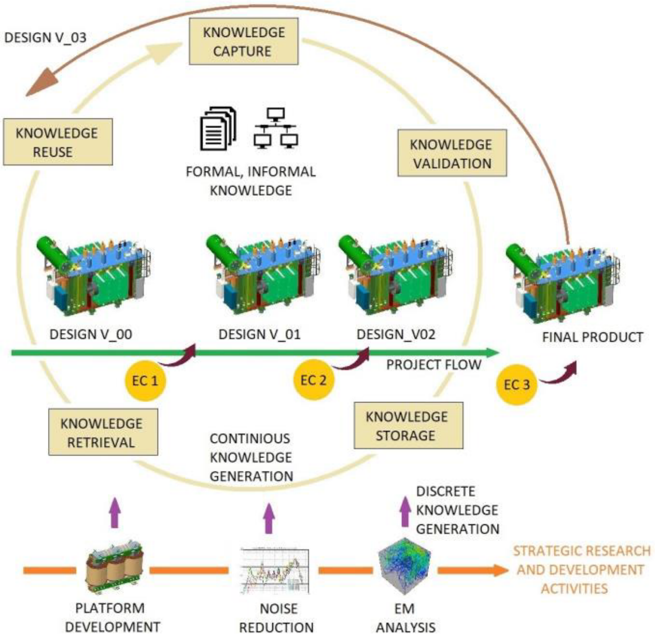

Figure 4: A framework for integrated knowledge management in OKP. After last minute changes before product delivery, project is always reviewed and corrected in case of possible repetitions in the future.

4. Discussion

This paper has presented the transformation of product development design for large power transformers into a competitive and smartly supported process. One-of-a-kind production has its own rules and specifics, as all design activities and efforts are influenced by completely customized products for known clients. Therefore, a robust design process well supported by IT plays a key role in creation of a digital twin and the product's final value. Based on a systematic analysis of the sample company, the paper proposed a model for the complete renewal of information system and working methodology, where reorganization was demonstrated in an increase of overall effectiveness.

Design for changeability, a design strategy developed to cope with engineering changes, incorporates the following four aspects: adaptability, robustness, agility, and flexibility. System architectures characterized by these attributes will yield great enhancements. It is possible to insert technology throughout the entire system lifecycle to ensure superior system capabilities and customized functionality. Opportunities for upgrade and ease of customization lead to high levels of attractiveness for customers or stakeholders. Design reuse aims to maximize the value of customization efforts by reusing successful past digital twins in whole or in part for future designs. More often than not, when a new design problem arises, it is solved through the modification of an existing design rather than performing the design process from scratch. Due to the complexity, associated cost, and general uncertainty of performing the creative design process, significant value exists in reusing design information. This paper's valuable contribution is the framework for integrated knowledge management in OKP. After last-minute changes and before the delivery of any one-of-a-kind product, the project is always reviewed and corrected for potential future repetitions, even if they are not expected. Knowledge for any new product is hidden in knowledge and experiences, gained during accomplished past products.

The conducted research demonstrates that the issue at hand is complex, wherefore its professional breadth requires the cooperation of the entire company. Constraints satisfaction problem (CSP) solver, developed internally by R&D department, has proved to support an initial stage of customized product design to a great degree. When introduced, the product development and design process made a considerable step towards robust and effective operation. The solver merged numerous structural calculations that were, up to that point, organized as separate independent spreadsheets. With functional links between all calculation chapters and the flow of parameters (input/output), the solver enables numerous calculations in a short time period. Functional links and progress bars eliminate human errors completely. Figure 3 presents the proposed initial design methodology framework. Defined input parameters are fundamental preconditions for preliminary design. In the preliminary design phase the general product architecture is defined by selecting an appropriate platform for each product subassembly.

5. Conclusions

The results of the presented IT support upon creation of the digital twin in the PD process are promising in multiple aspects and offer various opportunities for further development. Advanced parametric design enables an efficient configuration design process because all platforms are interchangeable due to their unified connecting interfaces. Parametric modularity also enables effective design iterations in the event of late design changes. The expert system forms the core of design activities and enables multilateral exchange of the parameters, increasing the robustness of the whole operation in the event of any redesign activities.

A direct consequence of implied renovation are savings, which were obtained in the performance analysis during a one-year test period. The total design time for product customization was reduced from 40 to 23 hours, especially the time necessary to complete a 3D design of the featured assembly (magnetic core), namely from 16 to 5 hours. The number of realized projects per year (per person) was increased by 33%. At the same time, the percentage of realized projects where engineering changes were necessary (rework) was reduced from 5 to 1%. The proposed framework is generalized, making it directly applicable in similar business environments and thus helpful for establishing the best-practice guidelines for promoting competitiveness in one-of-a-kind PD processes.

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Use of Textual Elements to Improve Reliability Prediction for Aircraft Component Behavior

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Abstract. Unplanned maintenance is a costly factor in aircraft operations. Predictive maintenance models aim to provide greater insight into future component and system behaviour. In the state of the art, a variety of statistical models and machine learning techniques, amongst others, are used to estimate component remaining useful life. These approaches commonly leverage technical information, such as sensor data. However, the use of data and techniques from other domains is not prevalent. One such example is the application of natural language processing to incorporate textual information, e.g. derived from pilot complaint data. In other words, does the presence and specific content of pilot complaints have potential to improve the predictability of component removals? In this research, data integration and processing from multiple disciplines are combined to address this question. Relevant words from pilot complaints are identified using a term frequency–inverse document frequency (TF-IDF) numerical analysis, after which the most relevant words are used as covariates in a proportional hazards model. Left truncation and right censoring is applied to limit the time-invariant nature of these covariates. The results in the form of hazard ratios indicate a hazard increase of several orders of magnitude with respect to baseline hazard, pointing towards potential value of including these words as predictive parameters.

Keywords. Predictive Maintenance, Natural language processing, Proportional Hazard Models

Introduction

In aviation, maintenance plays a crucial role in ensuring continued aircraft airworthiness, allowing for safe operations of worldwide aircraft fleets. Beyond safety, maintenance also is crucial in determining the economic feasibility of aircraft operations; the right level of maintenance will prevent unscheduled and costly interventions, while allowing for smoothly aligned scheduled interventions. To enable this, insight into when an aircraft – or more typically, one of its systems or components – will fail is key. The field that studies the remaining lifetime of an object is known as survival analysis in general, and usually referred to as reliability analysis in engineering applications. Scientists and practitioners in this field have come up with a variety of statistical models to give insight into remaining life-time. A substantial part of these models are parametric, such as the Weibull distribution [1]. Where more flexibility is required, non-parametric models such

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as the Kaplan-Meier Estimator [2] can be employed. Though many models are univariate, a subset of models allow for a multivariate approach to survival analysis, like the semi-parametric Proportional Hazards Model, or Cox model after its inventor Sir David Cox [3], which has been applied predominantly in healthcare, with some examples in the engineering domain [4]. In such applications, operational parameters or physical parameters such as engine oil condition [5] are typically used. In more recent research, machine learning techniques are employed to leverage the sharply increasing availability of sensor data to more fully understand component deterioration and failure, as part of the fields of predictive maintenance and prognostics.

Despite these advances, one could argue that the most comprehensive sensor of them all, the pilot, has been overlooked as a source of data for research purposes. The pilot produces information in the form of natural language which is captured in pilot reports and pilot complaints. This information has significant potential not only for use in airline operations and maintenance (where this potential is largely realised through current-day regulations, procedures and processes), but also for predictive purposes. Through the application of natural language processing to incorporate textual information derived from pilot complaint data, it may be possible to provide improved predictability regarding upcoming component failures. In other words, does the presence and specific content of pilot complaints have the potential to improve in-service performance? In this research, data integration and processing from multiple disciplines are combined to address this question in the form of a proof-of-concept approach.

This is an example of where it is necessary and valuable to consider the inclusion of methodologies and stakeholders from multiple disciplines. As such, the problem at hand provides an example that falls under the banner of transdisciplinary research. In particular, several essential characteristics of transdisciplinarity are met by the problem at hand, namely 1) a process that starts from a real-world problem; 2) collaboration between and contribution of knowledge from different disciplines; 3) a shared overarchting goal from research and practice [6-8].

In summary, the purpose of this research is gauge the usability of the pilot complaints as an external source of data, and thereby test the applicability and effect of using textual information to improve reliability estimation. The structure of the remainder of this paper reflects this focus. First, the approach employed to tackle this problem is discussed in more detail in Section 1. Subsequently, this approach is applied towards a dataset comprising component removals and associated pilot complaint data. Section 2 discusses the characteristics of the dataset and the subsequent implementation of the approach, as well as the results. Finally, conclusions and recommendations for future research are given.

1. Methodology

To tackle the inclusion of pilot complaint information within component failure prediction, the methodology as set out in Figure 1 is proposed. It comprises a number of distinct steps, which are discussed below, with attendant theoretical concepts being further explained where deemed necessary.

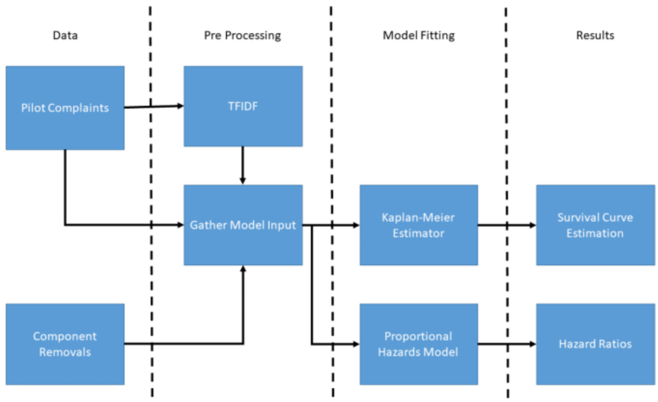

Figure 1. Methodological approach.

- **Data gathering:** the necessary data for estimating component reliability must first be gathered. This comprises pilot complaints and component removal data. The prior contain the textual data which must be processed to gather relevant modelling covariates (see below). The latter is primarily quantitative data which can be used to calculate baseline reliability characteristics. Section 2 describes the specific datasets used in this research in more detail.
- **Pre-processing:** before application in modelling and estimation, the data must first be pre-processed. For the component removal data, pre-processing involves cleaning, matching and selection of appropriate entries. More detail is again given in Section 2.
  To be able to use pilot complaint text as explanatory covariates within reliability models (see below), this text must first be converted to a numerical value. This pre-processing falls under the banner of natural language processing (NLP) [9]. In this research, pre-processing is performed using a basic natural language processing (NLP) technique, namely frequency-inverse document frequency (TF-IDF) as describes by Sparck Jones [10]. TF-IDF yields a measure of relevance for the processed text. In terms of the subject at hand, TF-IDF is used to score words based on how frequently they occur in the pilot complaints leading up to a removal, while correcting for its frequency in the entire corpus of pilot complaints. The scoring equation associated with the application of TF-IDF in this study is expressed in Equation 1 below.

$$a_{ij} = \log\left(tf_{ij} + 1\right) * \log\left(\frac{N+1}{n_j}\right) \quad (1)$$

  With a_{ij} being the score of term j in document i, tf_{ij} being the term frequency of term j in document i, N being the total number of documents in the corpus, and n_j being the number of documents that term j appears in.
  Model fitting: model fitting comprises the use of the pre-processed data to ensure two things: 1) modelling and estimating baseline reliability characteristics for comparative evaluation; 2) modelling and estimation reliability characteristics including the TF-IDF findings. With respect to 1), baseline reliability estimates are obtained by employing Kaplan-Meier

Estimators. The Kaplan-Meier Estimator, given below in Equation 2, is a method to estimate the survival function bases on (censored) lifetime data. As opposed to many statistical lifetime distributions, the Kaplan-Meier Estimator is non-parametric, meaning it does not adhere to a specific shape of distribution and therefore enjoys more flexibility.

$$\hat{S}(t) = \prod_{i:\, t_i \leq t} (1 - \frac{d_i}{n_i}) \tag{2}$$

With $\hat{S}(t)$ being the estimation of the survival curve, t_i being the time at which at least one removal occurs, d_i being the number of component removals, and n_i being the number of components that have not yet been removed.
With respect to 2), to allow for the inclusion of explanatory covariates, the Proportional Hazards Model is employed [3]. The PHM model models survival time while taking into account the effect of one or more explanatory variables, or covariates. The PHM model assumes time-independent covariates but time-dependent extensions are available in literature. In mathematical form, it can be represented as given in Equation 3. In this research, the main terms identified in the TF-IDF analysis are used as covariates within a PHM model (see Section 2) while assuming time-independence.

$$h(t|x) = b_0(t) \exp\left(\sum_{i=1}^{n} b_i (x_i - \bar{x}_i)\right) \tag{3}$$

with $h(t|x)$ being the hazard function, $b_0(t)$ representing the baseline hazard, b_i representing the regression coefficients, x_i giving the covariate values, and $\bar{x}_i$ representing the covariates' average values.

- **Results:** application of Kaplan-Meier Estimators gives rise to estimated survival curves, representing reliability behaviour without incorporating the effect of pilot complaint-derived explanatory variables. In constrast, the PHM model output yields hazard ratios, which quantify the positive or negative influence of explanatory variables on the component hazard function (i.e., the instantaneous probability of failure).

The methodological approach is implemented and applied in a case study as described in Section 2.

2. Case study

To investigate whether the inclusion of textual information (in the 'raw' form of pilot complaints) could be used to improve reliability estimation and prediction, a case study has been carried out on the basis of a dataset provided by an independent Maintenance, Repair and Overhaul (MRO) organisation. For confidentiality reasons, the company is not identified. The dataset in question is described in more detail below. Modelling assumptions and application of the modelling approach is briefly discussed before moving towards the results for a specific component within the broader dataset, which serves as an example of the opportunities and pitfalls of applying the approach as proposed in Section 1.

2.1. Dataset characteristics

The involved maintenance service provider has performed maintenance activities across multiple airlines, aircraft manufacturers and aircraft types. Records are kept of all parameters relevant to the technical state of the aircraft and span a period of time from 1987 – 2016.

The relevant subsets within the overall dataset concern component removals and pilot complaints respectively, as they form the main source of information for further analysis. The relations between these two tables are depicted in Figure 2. Each data entry has a unique identifier (primary key), being the ”CompId” for a component removal and a ”PilotId” for pilot complaints. Both tables have the ”AircraftSerialNumber” as foreign key, being the entry used to link the data entry to a data entry in a foreign table. The most important information the data is the ”Date”, as insight into the date of a component removal is crucial towards reliability modelling.

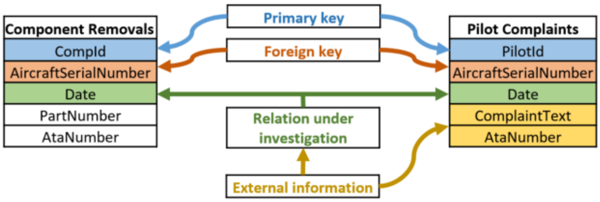

Figure 2. Primary datasets and attributes.

The component removals dataset spans a total of 476262 unique entries, whereas the pilot complaints comprises 428737 entries. However, not all of the data is suitable for further analysis as several issues contribute to significant dataset cleaning. The major three issues are 1) the appearance of non-English entries, where it has been decided to keep other languages than English out of the analysis to not complicate the NLP efforts; 2) absent aircraft serial numbers, where data entry has not been complete and therefore precludes linking specific component removals to specific pilot complaints; 3) quality of pilot complaint data, where the dataset has been constrained to post-2010 entries given that prior pilot complaint entries were sparsely and inconsistently captured.

In terms of NLP application, the pilot complaints that have been evaluated are typically comprised of sparse, keyword-like entries, sometimes including one or two brief sentences covering operational observations. To parse this information, entries have been made case-insensitive, with punctuation removed from textual entries. Furthermore, several synonyms (e.g. a/c, aircraft, airplane, etc.) have been merged into the analysis.

After cleaning, the datasets have been further reduced to enable a well-scoped, consistent data representation for use in analysis. The main steps here have been to constrain the datasets to occurrences from a single airline, within a single aircraft type, and selecting a top-five of components in terms of frequency of removals to arrive at a feasible scope of analysis. The results of the cleaning and reduction processes are given in Tables 1-2, with Table 3 providing an overview of the selected components and their removal numbers.

Table 1. Size of component removal data after various filtering and sampling steps.

	Component removals	Relative	Absolute
Raw	476.262	100%	100%
Filter dates	132.351	28%	28%
Missing registrations	102.451	77%	22%

Sample airline	21.761	21%	5%
Sample type	20.222	93%	4%
Sample components	3.101	15%	0.65%

Table 2. Size of pilot complaint data after various filtering and sampling steps.

	Component removals	Relative	Absolute
Raw	428.737	100%	100%
Filter dates	299.212	70%	70%
Missing registrations	295.746	99%	69%
Sample airline	96.951	33%	23%
Sample type	89.986	93%	21%

Table 3. Selected components (by frequency of removals).

Name	Description	Removals
Component 1	Oxygen bottle	2516
Component 2	Flow control valve	207
Component 3	Display unit	196
Component 4	Pressure Regulating Shut-off Valve	194
Component 5	Landing Light	176

2.2. Model assumptions and application

The main assumption to consider in the Proportional Hazards Model is explicitly part of its name. The hazard is assumed to be proportional to the baseline hazard. Equation 3 shows that the partial hazard merely scales the baseline hazard. Another assumption that follows from the model definition and the proportionality assumption is the fact that the effect a covariate has on the baseline hazard is constant in time. This last assumption is challenging regarding the nature of this research, since information from pilot complaints is very time-variant. Information is presented at some moment in time while being unknown before, and this information might become less relevant in time. This phenomenom is further illustrated in Figure 3, which depicts the situation where the birth is defined as the moment of installation of a component. The information in the pilot complaints is added somewhere between birth and death, death being the moment of component removal. It is evident that this information was not yet known before the onset of the pilot complaint. The covariate representing the pilot complaint or its content is therefore time-variant. Figure 4 shows the situation where the birth moment coincides with the onset of the pilot complaint. The information presented in the pilot complaint is known during the entire timeline and conceptually is not in violation of the proportionality assumption. The birth is therefore defined as the onset of each pilot complaint.

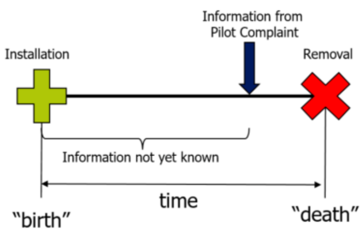

Figure 3. Moment of installation as birth.

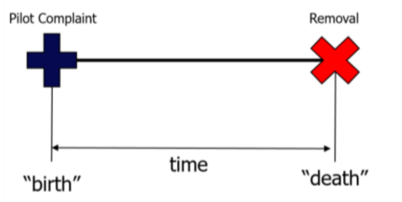

Figure 4. Moment of pilot complaint as birth

For each pilot complaint, the values of the following covariates are determined. The covariates consists of endogenous covariates and exogenous covariates. The former originate from the component removal data itself (and comprise variables “Year”, “Fresh” and “Summer”), while the latter originate externally from the pilot complaint data. The following list give an overview of the covariates used in this research:

- **Year:** The year of complaint can gauge the effect time has on the hazard ratio.
- **Fresh:** This covariate has a value of 1 when the previous component removal was within two months of the pilot complaint under consideration. This is used to judge whether a recent installation has an effect on the hazard.
- **Summer:** This covariate has a value of 1 when the pilot complaint falls within the airline summer schedule and is used to discern any seasonality effects.
- **PN:** This covariate has a value of 1 if the part number is mentioned in the complaint text. This is used to analyze the lifetime patterns when it is known in advance that a removal will occur due to the pilot complaint in question, in effect serving as a validation set.
- **ATA:** This covariate is used to determine the effect that mentioning the specific subsystem has on the hazard.
- **word:***: This covariate has a value of 1 if the word represented by the asterisk is mentioned in the pilot complaint. This is used to measure the effect of certain words on the hazard.

2.3. Results

The TF-IDF complaint processing, Proportional Hazard Model and Kaplan-Meier Estimators have been applied to the selected 5 components (see Section 2.1). Here, some in-depth results are presented for component 5: landing light, as a representative case. Findings for the other components are briefly summarized at the end of this section.

The TF-IDF analysis for component 5 is represented in Table 4. It is clear that words that are functionally related to aircraft landings feature highly in the output. In this example, and in general as well, term relevancy quickly tapers off, indicating that specific words are relatively dominant in specific complaints.

Table 4. Overview of TF-IDF scores for Component 5: Landing Light.

Word	TF	DF	Score
Landing	30	3147	27.78
Extended	7	161	27.35
Retract	16	548	21.03
Lh	34	8061	20.28
light	5	20993	20.03

Results for the endogenous covariates are shown in Figure 5 and Table 5. It is clear that having information on the ATA chapter improves reliability estimation through the adjusted hazard rate - ATA scales the baseline hazard by 60% while being statistically significant. The same is true for the variable “year”, though the effect is reversed and less pronounced in size.

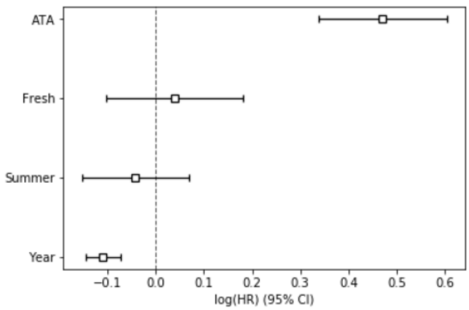

Figure 5. Forest plot of hazard ratios of Proportional Hazards Model fit of Component 5: Landing Light.

Table 5. Summary of Proportional Hazards Model characteristics for Component 5: Landing Light.

Endogenous variable	Coefficient	Exp(coefficient)	p-value	Proportionality assumption
ATA	0.47	1.60	<0.005	Met
Fresh	0.04	1.04	0.59	Met
Summer	-0.04	0.96	0.45	Met
Year	-0.11	0.90	<0.005	Met

Results for the exogenous covariates, i.e., the application of the Proportional Hazards Model for the four best scoring words in the TF-IDF analysis for this part, are shown in Figure 6. Note that the analysis for the word ”extended” is missing, due to excessive multicollinearity. Of the words, ”lh” misses statistical significance. The word ”retract”, although statistically significant, has a large standard deviation, as shown by the wide whiskers. The word ”landing” is the best performing word in this analysis, showing a hazard ratio of almost three, while being statistically significant and respecting the proportionality assumption.

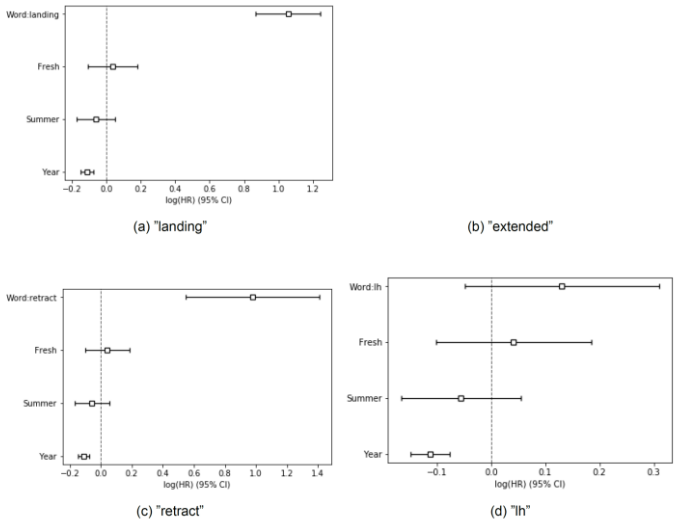

Figure 6. Forest plots of hazard ratios of Proportional Hazards Model fit of Component 5: Landing Light for different words.

Finally, Figure 7 shows a comparison between the Kaplan-Meier Estimator (KME), the adjusted hazard rate using the best-scoring word ("landing") and having the part number mentioned in the retrospectively added action in the pilot complaint. The latter is for validation purposes and shows the maximum predictive signal that one could obtain in a perfect world from textual entries. It is noticeable that including the word landing gives a slightly improved prediction of future failure behaviour, but does not come close towards full failure predictability as implied by having all information on complaint initiation, troubleshooting and resolution.

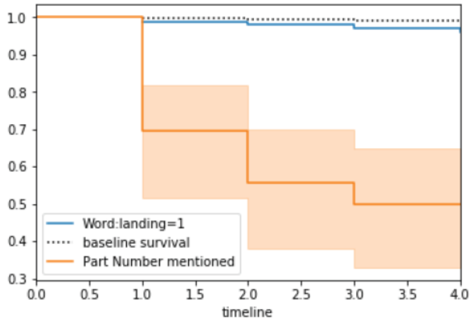

Figure 7. Comparison between Kaplan-Meier Estimator (baseline survival curve), KME with Part Number indication, and Proportional Hazards Model for Component 4: Landing Light for Word:landing.

Extending this analysis to other components shows similar patterns. For several components, the presence of multicollinearity precludes obtaining reliable results for specific words, but in general, the analysis of specific words in pilot complaints adds some increased predictability for component removals. However, the full potential of natural language processing of pilot complaints for forward-looking purposes is limited, unless the complaints are more detailed or incorporate maintenance troubleshooting information as well.

2.4. Discussion

Other situational factors may be at play which can further enrich the analysis provided here. For instance, the type, severity and frequency of complaints (especially in closely-spaced sequences) may help to distinguish slow- and fast-moving deterioration of components. Additional sources of textual information (such as maintenance inspection and shop findings) may further enhance reliability estimation by correlating pilot complaints with detailed characteristics (such as observed failure modes) associated with component removals, though sample sizes may be too small to find statistically meaningful results.

In terms of in-service implications, one critical aspect may be to consider the benefit of having an 'early-warning' function through real-time analysis of incoming pilot complaints. From this perspective, a knowledge-based diagnostic capability may be constructed by matching pilot complaints (or other sources of textual information) with prior cases and associated maintenance tasks.

3. Conclusions and recommendations

This research has presented a successful proof of concept, highlighting the potential use of textual information to enrich and improve reliability estimation. The hazard ratios resulting from the Proportional Hazards Model provide strong evidence for a statistically significant effect the information from the pilot complaint has on the hazard of a component removal. This effect however, is measured with respect to the baseline hazard. While the hazard in some cases increases more than sevenfold, one must also consider the absolute effect this has on the expected ”mortality”, which is severely limited by the short period under observation (in order to preserve time-independence). Furthermore, the limited descriptive content in the pilot complaints and the very simple NLP approach tested here do not provide deep insight into predicting towards future removal events.

These limitations can be addressed to some extent by considering more advanced NLP techniques in analyzing textual information that may be relevant towards component removals, especially techniques that (automatically) group synonyms or syntactically similar words. Furthermore, the major assumptions that had to be made with respect to time-invariant behaviour could be resolved by considering time-variant proportional hazard models. However, this would come at the cost of computational performance.

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Parametric Modelling of Steel Connectors in a Glulam Based Post and Beam Building System - Towards a Flexible Product Platform Approach

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Abstract. House building projects are distinctive, and the degree of customisation creates bottlenecks in the design process and challenges for production, which results in longer lead time and higher costs. Aligned with a product platform approach, previous studies have introduced cost-effective approaches such as standardisation, modularization, configurators, etc. Still, components that cannot be completely modularized and configured due to high complexity level, may require a lot of engineering efforts during development. A platform approach that can be used to support engineer-to-order products that change over time still needs to be explored. The application of parametric modelling to automate the design process in the construction industry has the potential to further increase both the design and production efficiency. Thus, the objective of this research is to apply parametric modelling in the design of steel connectors used in a glulam based post and beam building system as part of a flexible product platform for increased design and production efficiency. A single case study has been carried out with a Swedish multi-storey house building company. Empirical data were gathered from a workshop with the design team followed by interviews, and document analysis. A computer-supported method for the steel bracket connectors has been developed, that connects post and beam components with pre-defined rules and constraints as part of the platform development. The result contributes to expanding knowledge about the development of a flexible product platform for improved design process and downstream production of customised components with parametric modelling support in the industrial post and beam buildng system.

Keywords. Industrialised house building, Product platform, Parametric modelling Engineer-to-order, Building Information Modelling, Glulam, Post and beam.

Introduction

The housing market in Sweden has been undergoing a substantial price increase. The general price level in Sweden is relatively high compared to many other European

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countries [1]. The growing production costs of house building have been highlighted as a major barrier for the housing market [2]. In fact, companies are constantly looking for approaches to increase productivity and manage the frequently increasing cost [3]. Several initiatives have been performed to increase the efficiency of production and to solve on-site issues as part of continuous improvement. However, the design phase of industrialised house building (IHB) is generally perceived as being inefficient and time-consuming [4] and found as the bottleneck of productivity in building construction [3, 5]. The role of product descriptions have changed over time and more and more tailor-made products lead to generate concepts such as engineer-to-order (ETO), modify-to-order (MTO), configure-to-order (CTO) and select variant [6, 7]. Customization or unique needs from the customer has been identified as a common challenge facing by the IHB industry [8], where projects differ with unique requirements over time. Product platform strategies and standardisation efforts have had a significant impact on the development time and cost reduction [9, 10]. Together with a product platform approach, many previous studies have introduced approaches such as modularization, configurators, etc. that supported to a great extent to become cost-effective. However, some components that cannot be completely modularised and configured due to its high level of complexities required a lot of engineering activities during its development. Transdisciplinary engineering can be supported by a disciplinary ability to respond to different stakeholder's needs and demands. Engineering methods for improved ability to design and manufacture customized solutions could potentially support engineers and construction companies to contribute in transdisciplinary development projects. Platform approach for the component-based product where reusing of design assets has already been a research topic and this is more accountable for the standard products. In other words, a platform strategy that can be used to support the customised product that changes over time still needs to be explored [11, 12]. Thus, there should be some dedicated support that could be used to deal with products having ETO nature and to design it more efficiently and ensure producibility.

Companies start to see the benefits of digitalization in construction design and today's CAD systems can be applied for much more than 3D modelling and the generation of drawings [13]. It is possible to automate the design process if the construct of any complex artefact is suitably restricted by adhering to a library of predefined components and assembly details [14]. In the building industry, the implementation of design automation has increased productivity [15] by using parametric modelling to automate Building Information Modelling (BIM) [16]. Thus, the objective of this research is to apply parametric modelling in the design of steel connectors used in a glulam based post and beam building system as part of a flexible product platform for increased design and production efficiency.

1. Theoretical background

A product platform is a collection of assets, which are shared by a set of products sorted into components, processes, knowledge and relationships [9, 10]. They pointed out the benefit of the platform that, "by sharing components and production processes across a platform of products, companies can develop differentiated products efficiently, increase the flexibility and responsiveness of their manufacturing processes, and competitive in the market with competitors that develop only one product at a time." The concept of design assets offers a new way for efficient customisation, reuse and standardisation by introducing and structuring platform elements that are traditionally not used in a platform setting [12]. The concept of flexible product platform is first proposed by Suh, De Weck [17]. Flexibility is defined as *''the property of a system that is capable of undergoing specified classes of changes with relative ease''* (ibid). The flexibility of a product platform is its capability achieved by modifying parameters of flexible elements [18].

BIM is not only a computer application supporting the 3D object modelling of buildings, but also allows both automatic parametric generation of designs that respond to various criteria and the prospect of computer-interpretable models and automated checking of designs after they are generated [19]. The knowledge representation during the design phase is certainly becoming an important issue in the area of design automation [14]. Eastman, Lee [20] emphasises that the rule-based systems apply rules, constraints or conditions to a proposed design. Parametric Design is "the process based on algorithmic thinking that enables the expression of parameters and rules that, together, define, encode and clarify the relationship between design intent and design response" [21]. Parametric modelling feature permits regeneration of geometry based on geometrical constraints [22] and allows to integrate domain-specific knowledge using explicit mathematical expressions [16]. According to Singh, Gu [23] the modelling and technical flaws can be reduced as the set of rules for building modelling are predefined using parameters in BIM. Implementing Parametric and Generative Design techniques in Glued laminated timber (GLT) could improve the overall efficiency and can be considered an effective tool for improving the capabilities of design and manufacturing processes in the building industry [24]. Parametric constraint-based design within BIM platforms offers an automatic design validation, where the model is automatically updated to adapt changes [25].

2. Research Methodology

The research framework used for this study was Design Research Methodology (DRM), proposed by Blessing and Chakrabarti [26]. This DRM framework comprises four iterative stages used for conducting research in the engineering design field. DRM is used as a framework for the entire research project and this article presents the outcome of the two final stages of DRM with an emphasis on the Prescriptive stage. The support was proposed to improve the current state of the design process in the case company in the prescriptive study stage and an initial evaluation was done with the designers as part of the descriptive study II phase.

The study was qualitative in nature with a combination of a literature survey and a single case study by linking a Swedish multi-storey house building company. Empirical data was collected from a workshop, semi-structured & unstructured interviews and document analysis. A workshop session was conducted by including both design engineers and the management team. This section initially helps to brainstorm the needs, current challenges facing and to understand the vision to achieve from the company point of view. A project team has been formed as an outcome from the workshop with the aim of different development and improvement activities where the case of steel connectors was in the priority list. The team includes a CAD programmer, two structural engineers and the researcher. In addition, four semi-structured interviews were conducted with key persons who have extensive experience from the design department. The respondents were: the design manager, senior structural engineer, CAD programmer, and structural engineer. Additionally, unstructured interviews were conducted with the key designer on a frequent basis in order to understand the current knowledge, challenges and opportunities during the design of connectors. The interviews were audio-recorded and transcribed before the materials were analysed. Document analysis was initiated parallel with the interviews to get in-depth knowledge about the previous projects. Documents related to the design of the connectors from previously finished projects were reviewed. The reviewed documents include building models, part drawings, design templates, bill of materials, component library etc. The bracket connection was chosen as the experimental object where the parametric modelling was applied. At first, the standard parameters and dimension for the bracket connection were formulated from the weekly meeting with the project team. The algorithm was developed as a Plug-in application connected to the BIM tool (Tekla Structures) using Visual Basic (C#) and the open API in Tekla Structures with the support of CAD Engineer. The input parameters for the connection are defined with user interface (UI) support of Plug-in used in Tekla. Finally, an initial evaluation was carried out with the designers to verify the results generated.

3. Case company description

The case company is one of the leading manufacturers of glued wood in Europe. They developed a unique building system on the multi-stored house building market and launched it in 2007. The system was developed based on the prefabrication technique and named as Trä 8 building system and can be used for up to 8-meter span. This building system can be categorized in the timber based post and beam type of industrial building. The fundamental part of the system is the idea of "Big Size Pre-Cut", where a high level of prefabrication of large building elements and sets of material is developed through efficient production. The main components of the building system include of post, beams, trusses for stabilization which is made of glued wood, floor elements and roof elements made of Kerto material and glulam, and steel connectors. GLT is a widely used structural engineered building material composed by at least two parallel laminations of wood which may include one or two boards next to each other (BS EN 14080:2013).

4. Case findings – Design of steel connectors used in the buiding system

Steel connectors are precisely engineered components used to transfer loads from one component to another component. They are used, for instance, to transfer loads from different floors to the foundation through the vertical columns. Each connector is designed to function in different ways and to transfer different magnitude of loads from the building to the foundation. There are four main types of connectors commonly utilized in the building system by the case company as shown in Figure 1.

(1) Column footing: This is the most common type of column footing connection for the building system. On top of a cast-in reinforced steel plate, a second plate with 4 threaded rods are welded on site. The column is delivered with a third plate mounted in the factory using glued-in threaded rods. The third plate uses nuts and washers and the lower washer could be levelled using a plane laser before erecting the column.

(2) Column footing with trusses: When trusses are used in the building, this type of connection is ideal for footing. Trusses are connected to the column footing with the use of dowels. First, the welded plate is mounted with the column in the factory and then, the whole assembly is connected to the reinforced concrete with foundation bolts at site.

(3) Bracket: This type is used to connect the column with the beam in the building system. The main purpose of these connectors is to transfer the loads from the floors to the vertical columns. Additionally, they function in transferring the horizontal and vertical loads to the wooden trusses.

(4) Truss connection: To stabilize the building structure from the horizontal loads, wooden trusses are used. The element consists of two columns with beams and diagonals connected with slotted in steel plates fastened with dowels.

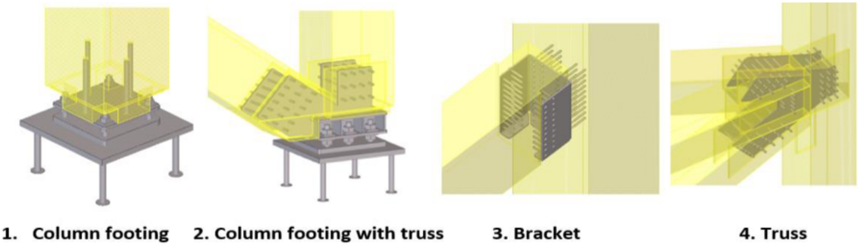

Figure 1. Different types of steel connectors used in the building system.

The connector design process generally involves structural design and modelling of connectors as shown in Figure 2. The structural design normally begins by understanding the scope of the project and the different requirements of the customer, i.e., type of building, number and height of floors, apartment details etc. Identifying the different loads acting in the building is the first step of the structural design. This includes ordinary forces from all loads such as dynamic loads, static loads and special loads. Loads imposed on the building should be transferred to the foundation to keep the building stable. Therefore, connectors can be considered as the most critical component of the building system, to transfer both vertical and horizontal forces.

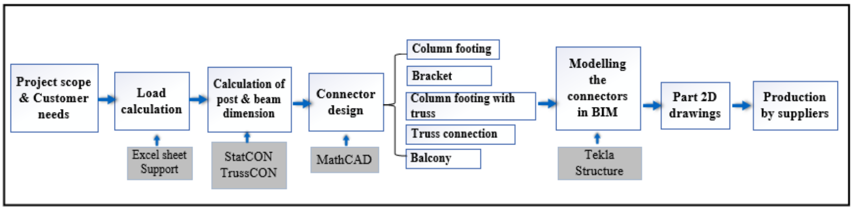

Figure 2. Design process of the steel connector.

The subsequent step is to find out the dimension of glulam post and beam where STATCON or TRUSSCON is used as the tool for performing it. The calculation starts with the beam as the dimension of the beam is necessary to calculate the dimension of the post. The design of connectors can be made when the required loads and dimension of members are calculated. Math CAD is used to design different types of connectors. For example, the vertical load, horizontal load, the dimension of beam and size of screws that goes into the post are the main input data for calculating the brackets. The bracket design is governed by the load calculation. First, the dimension of beams is calculated for the entire structure. For simplicity, the value of different dimensions is kept as low as possible. Once the dimensions of beams are decided, the structural engineer can determine the amount and length of screws needed for each beam cross-section. The modelling of brackets is initiated when the modelling of beam and column members has been completed. This is because the information about the number of screws can only determine from the beam profile. The longest beam with a higher force is often used as a reference for all other beams with a similar height to avoid the calculation of individual beam separately. Likewise, different variants of brackets can be reused in different parts of the building. Connectors for balcony is not included in the building system as it differs depending on the customer requirements. The next step is the modelling phase and all these values are forwarded to CAD designer as AutoCAD drawings, who take care of the modelling of building and detailing of different components. Tekla Structures is used as a tool for modelling the whole building and creating a fully detailed production model of the building components. The program generates 2D drawings and machine files using the information in the building model. Finally, all the drawings and values in digital format are forwarded to the suppliers who produce the connectors. For some connectors, pre-assembly is required before the final assembly on site. The collision between different elements in the connector has been recognized as the major challenge in the design. So adequate control is required while defining different parameters and its dimensions. Moreover, any change in the size of members or the height of the floor would generate a new variant of bracket which is the main challenge for designers.

5. Application of parametric modelling in the bracket connection

The prescriptive research activity has been conducted through two main stages: coding the method and testing the algorithm for modelling. The bracket connection was selected as the modelling object as this is one of the commonly used and challenging components of the existing platform and manual modelling is time-consuming and prone to errors. The first phase refers to programming the parametric algorithm for brackets in a Visual studio, where the parameters were defined with rules, constraints, dependencies and boundary conditions. To perform its calculations, the algorithm requires specific inputs that must be manually created. For designing the brackets, the most significant inputs are the value of the horizontal and vertical load, the dimension of primary (post/column) and secondary members (beam) and number of screws on the members. A logic has been followed while programming to create the rules for the parametric features of the brackets. In this stage, all the standard parameters and their respective dimensions of the bracket connections have been defined. The rules and constraints that govern the different design have been set with many alternative conditions. Coding begins with defining the values as in the table shown in Figure 3.

	Parameters	Dimensions
1	Material grade of plate	S355J0
2	Number of screws in primary element	24
3	Number of screws in secondary element	24
4	Tolerance of glulam width	2 mm
5	Tolerance of glulam length	5 mm
6	Dimension of screw in primary element	WFD 8 X 100
7	Dimension of screw in secondary element	WFD 8 X 70
8	Option : Predrilling	Yes
9	Option : Sub-assembly	Yes
10	Thickness of plates	5 mm
11	Minimum edge distance : Parralel to grain	80 mm or 7 times diameter of screw which comes higher
12	Minimum edge distance : Perpendicular to grain	25 mm or 3 times diameter of screw which comes higher
13	C to C distance of screws : Parralel to grain	5 times diameter of screws
14	C to C distance of screws : perpendicular to grain	4 times diameter of screws
15	Coating	Galvanised / Clear coat
16	Option: Reccessed in secondary beam	Yes, 3 sides
17	Bending radius	2 mm

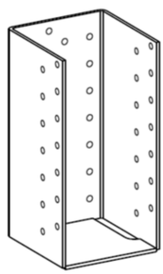

Figure 3. Standard parameters and dimensions for bracket connection.

The next step was to specify different coordinates of brackets. Then, add plates to different coordinates in order to merge with the plates. The thickness of the steel plates is always 5mm and it never changes. Subsequently, postion of different holes and details of screws that should be generated in the plate are specified. Finally, the cutting of the beam is also defined to ensure that the beam is properly seated in the bracket.

The second stage was the testing phase and the use of the algorithm in the BIM environment (Tekla structures). Here, the algorithm performs a geometry analysis to identify the key inputs for further process. The bracket is then inserted to the BIM-model using the Plug-In application where the CAD-engineer can specify the information about the needed screws in the UI of the Plug-In. The size of the beam and column is fetched into the Plug-in from the model. Using this approach, the connection is geometrically dependent and placing of the beam and column and will adapt to any changes of location or dimension. When using parametric modelling in BIM, there are four steps to follow, 1. Select the primary member, 2. Select the secondary member, 3. Add the number of screws in the primary and secondary members, 4. Select the type of screws. These parameters are the input values provided in a dialogue box, as shown in Figure 4.

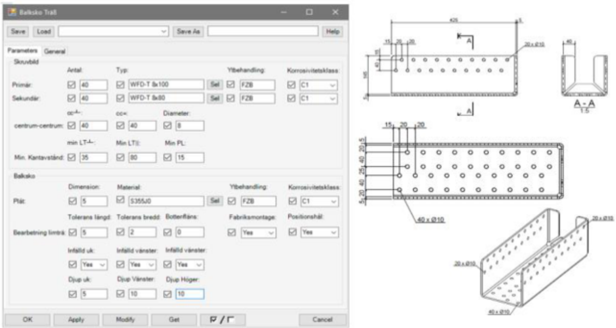

Figure 4. Parametric representation of bracket connection.

The procedure for generating other types of brackets is generic, and the variants would depend on the beam size used in different parts of the building structure. When designing the brackets, the algorithm automatically checks the rules that are based on the configuration of the objects, their relations or attributes. Here the width of the beam basically decides the number of screws that should generate in the bracket, which in turn governs the height of the bracket. How many screws that can fit in one row would decide the height of the bracket. The algorithm will detect the number of screws and adjust the real height to avoid the collision. It is important that the height of the bracket should be less than the height of the beams. The distance to the first row of the screw is specified from this top of the beam. The primary screws from both sides should be short enough to avoid the collision. Therefore, it is important to define the code with a correct offset in order to avoid the collision. However, designers run a verification check to confirm any collision between screws. The same variant of the connector can be generated in different parts of the building if the beam size is identical. The rules are defined for adapting by itself. Thus, the designer can save time and effort by avoiding the repetaed design of the same connectors. If the size of the beam is different, the parameters should change, and the bracket will follow the predefined set of beam sizes and generate a new solution. Thus, there should be different codes for different types of connections.

6. Discussion

The analysis of building components shows that the modelling and detailing of steel connectors accounts most of the design time, which was acknowledged by the respondents. The case company produces glulam components and all associated designs are relatively standard. However, steel connectors were identified as the most challenging part of the building system. About 20-30% of the time would be sufficient to design all other components of the building system such as glulam post, beam and, floor elements and remaining is dedicated for the connectors. CAD engineer states that "*the technical detailing of connectors remains as a challenge as new connectors have been designed in every project*". Currently, limited support is available to streamline the design process and challenging to reuse variants within and across projects. The main reason is changing requirement of the building structure over time and the connectors projects an engineer-to-order characteristics [7]. Therefore, the company was in need of a distinct strategy to improve productivity in the design process. One type of code has been created for the bracket connection, from which several variants of connectors can be generated. So, this can be considered as a design asset in a platform for the bracket connection from which different sets of solutions can be derived [12].

The main objective of this study was to improve the current way of connector design and increase the ability to respond more quickly to customer-specific requirements to enhance producibility. An initiative was taken by the project improvement team by applying the parametric modelling approach in bracket design. The analysis reveals that this modelling approach can be related to a product platform explained by Meyer [9], from which a stream of different variants of connectors can be efficiently developed and produced with an emphasis on the knowledge assets defined by Robertson and Ulrich [10]. In other words, different bracket variants can be derived from the same platform, by predefining the knowledge assets [14] and specify the standard process to execute it. Here, reuse is achieved not by sharing the components rather by sharing the knowledge asset [12] which is pre-defined by various set of rules and constraints using the algorithm [16, 22]. The flexibility of the proposed product platform is the ability to rapidly generate a design solution to accommodate both predicted and unforeseen changes through the reuse of design knowledge and computational methods [18]. On this developed platform, knowledge assets are predefined in such a way that the connector can be created that can adapt to dynamic customer requirements by adjusting its structural parameters [17]. The algorithm would take care of advanced geometry that goes into the different bracket connections that the company currently possesses. Thus, flexibility is achieved with the support from parametric modelling. Manual design can be avoided as complete solution is generated with different configurations. Moreover, platform architecture and how it is communicated is important when defining the rule of different configurations [9]. The execution is the same, and faster than selecting different components from a component library where set of solutions are pre-defined. Thus, a robust platform offering a rule-based approach can be developed with the help of parametric modelling. It has the ability to pre-check a model, such as geometry overlaps, rules for attribute and name, object existence and others, more detailed check [20]. To achieve this flexibility in connector design, the designer must identify the components to be modified and then determine how such changes propagate through different attributes.

Developing a rule-based product platform leverages the parametric modeling capabilities of BIM tools to automate the modelling process. The result shows that easy and quick modelling of connectors is possible, and the connections can be made automatically with options for adapting to the alternative design settings that enable design automation [13]. With parametric modelling approach, the rules and constraints are defined to control all possible collisions between these elements. The elements of the bracket are automatically modified, which shortens the modelling time and improves the quality. When members sizes are changed, the connections are automatically alternated according to designer's settings, which allows the accurate design [25]. Moreover, individual drawings can be generated from the model by using the filter option in Tekla that helps to avoid detailing of each bracket from scratch. The algorithm has been programmed in order to handle fluctuating customer requirements and to maintain the capabilities of a building component having ETO characteristics. Furthermore, this new method could support the existing platform to evolve as the algorithm can be updated and add more functionalities to become more agile. Thus, the study presents a novel approach in creating flexibility for the bracket platform with boundary conditions from a post and beam based construction. The case company can be able to make an impact on their design lead time with this approach by generating algorithms for all different types of connectors used for the building system. The result show that the integration of parametric support to BIM would assist designers in decision making and significantly reduces the possibility of inconsistencies. Therefore, the critical factors addresed are the time, cost, customisation and flexibility aspects when implementing parametric modelling approach in the design process [8]. The main limitation of parametric modelling is that skilled workers are required for coding the rules in computer language. A logical approach should be followed and high-level of expertise is needed to define, maintain, managing the algorithm over time, and verify the result to get a accurate outcome. It would consume a considerable amount of time and effort in the beginning while creating the algorithm. The result generated from this research is limited to a type of steel connector (bracket) used in the building system. As a future study, the case company can generate algorithms for other types of connectors for a significant impact on design improvement and validate the results. Moreover, the applicablity of the methodology can be tested and scaled to other type of building systems with components having ETO nature and be considered for future studies.

7. Conclusion

This article presents the development of a flexible product platform to support the design process of industrialised house building. A case study illustrates how a flexible product platform with parametric modelling approach can be developed and used to design building components having an engineer-to-order characteristics. The result shows that the parametric modelling based product development in the building industry offers flexibility in the design process and supports customization. The findings also provide an overview of the magnitude of the challenge associated to the design of connectors for glulam post and beam buildings. Thus, parametric modelling is a promising design automation tool to generate customised building components and facilitate and build a flexible platform. The approach provides a path forward to improve the design process of connectors and offer a flexible building system that can respond to future uncertainties. The results reveal that the way in which the flexibility is incorporated in the component such as the beam profile, number of screws in primary and secondary member, should consider when designing a flexible product platform for bracket connection.

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Knowledge-Based Assisting Tools – Real Life Inspirations

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Abstract. These days are characterized by globalization and digitization. The scope of both these phenomena is growing in an evolutionary manner. At the same time, knowledge resources are increasing, and in many cases specific knowledge is becoming globally available, and its representation is to a large extent differentiated, more and more efficient, and more effectively digitized. The techniques resulting from the above-mentioned trends allow wider and simpler knowledge sharing, for more frequent and inspiring compilation and interaction of different sources of knowledge. Classic formal and informal methods and tools based on modelled knowledge must take into account these phenomena and processes. Due to the specific level of development of computer resources and knowledge modelling tools, a defined infrastructure of methods and tools has come into being. We define this stage of knowledge modelling as level I. The processes of creating and generating knowledge is also an interaction between various sources of knowledge: human and computer. We define this stage of knowledge modelling as level II. In addition to the approaches mentioned above, there is a group of tools that were created by artificial intelligence, e.g. case-based reasoning, machine learning, data mining, etc. We define this stage of knowledge modelling as level III. Far-reaching specialization is progressing in many real-world processes. Consequently, the used tools, including computer tools, are subjected to this process. An example of such a solution can be a system which is used to support the design process of certain selected types of manufacturing machines.

Keywords. Engineering knowledge modelling, Knowledge-Based Engineering, assisting systems in engineering

Introduction

These days are characterized by globalization and digitization [1, 2]. The scope of both these phenomena is growing in an evolutionary manner. At the same time, knowledge

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resources are increasing, and in many cases specific knowledge is becoming globally available. Its representation is to a large extent differentiated, more and more efficient, and more effectively digitized [3-9]. Knowledge is recorded and stored in digital knowledge repositories which are usually dedicated to specific classes of applications.

The techniques resulting from the above-mentioned trends allow wider and simpler knowledge sharing, for more frequent and inspiring compilation and interaction of different sources of knowledge. They also enable the user to return to existing resources, making them materially helpful in reflection. Knowledge in a formalized form can become the basis for expanding the possibilities of classic tools used in various professions by providing multi-variability, comprehensiveness, flexibility, and a higher level of adaptation to existing realities.

Classic formal and informal methods and tools based on modelled knowledge must take into account these phenomena and processes. There is an urgent need to create new approaches and formalisms that are able to tie classic modelling and knowledge management tools with current trends.

The construction of tools whose operation is based on knowledge often depends very strongly on the quality of the acquired knowledge, and on how deeply the captured knowledge is acquired, modelled and preserved. These elements of knowledge processing processes have the greatest impact on the quality of implemented solutions, but they are usually labour-intensive.

Due to the specific level of development of computer resources and knowledge modelling tools, a defined infrastructure of methods and tools has come into being. Here we can obtain tools for consolidating formal, informal, advisory and encyclopaedic knowledge, where knowledge is subject to detailed verification and validation. The knowledge is published in one way or another, is available online, and its representations are mainly multimedia with annotations. The evolution process of the knowledge is captured with the help of the versatility tool. We define this stage of knowledge modelling as level I [3, 4].

The processes of creating and generating knowledge is also an interaction between various sources of knowledge: human and computer. These are sequences of actions that take the form of associations, inferences, and reflections. Remembered or saved in a different way, they often become the source of inspiration to develop something new. For that purpose, the knowledge sources require different representations - multimedia, commented multimedia, supplemented with references, explanations, associations, which are sometimes based on ontologies, etc. In many of these activities they support the so-called assistance systems based on knowledge / information, group / personal management concepts using a variety of different methods. We define this stage of knowledge modelling as level II [3, 4].

In addition to the approaches mentioned above, there is a group of tools that were created by artificial intelligence, e.g. case-based reasoning, machine learning, data mining, etc. These tools require a certain quality standard of the processed data, which are based on certain formal representations. In this case the modelled problems can be the effect of mixing or converting the representations used in the approaches discussed above (levels I and II). There is an increasing demand for tools supporting this class of tasks, i.e. tools ensuring high quality of obtained data sets. We define this stage of knowledge modelling as level III [3, 4].

The authors of this work based their findings on an analysis of the literature in the field of methods and tools for modelling engineering design knowledge. They refer to both achievements that are treated as classic [10-14], as well as relatively new and innovative solutions [1-9, 15]. They compare the above achievements with the facts that take place in realistically functioning forms, at present, in real industry. These considerations are multi-threaded and relate to facts observed at different levels of modelled reality. The paper refers to both industrial realities and modelling of real, functioning engineering knowledge.

The analysis of the functioning of knowledge-based tools in real industrial conditions cannot be reduced to the tools themselves. Design processes are also important: their characteristics, degree of innovation, level of advancement of obtained design solutions, assessment of how the tools contribute to the creation of a high level of construction. In order to provide this context, the paper presents the substantive characteristics of a specific, industrial design process implemented and supported by means of tools based on knowledge. While performing this characteristic, it is impossible not to notice the influence of a number of different, other factors on the final results obtained in the implemented design processes. These are, e.g. the level of computer resources used, the degree of preparation of designers in terms of their knowledge of computer aided design methods, and many others, considered as factors evolving over time. The visible evidence of success are the events which had a breakthrough character and a very significant impact on the structures created. The paper analyses such events and presents their components and factors. In all cases, specific knowledge, decisions and conditions were followed by specific successes to varying degrees.

The team (in a changing composition) to which the authors belong has been dealing with the subject of modelling engineering knowledge for 30 years [16-20]. The above-mentioned phenomena, globalization and digitization, have also been overlapped by the attempts of the team members to implement various methods and tools based on the modelling of engineering knowledge in real industrial applications at different levels and at different periods of time. It was also a period of intensive development of engineering design knowledge, taking place both globally and at the level of individual design offices.

Due to the wide range of issues and content, as well as the time span, the authors chose case studies as a method of presenting their achievements.

1. Case study

The authors of this study cooperate with a company dealing with the design and construction of various types of production lines for plastic sheet metal processing [3.4]. It is a relatively small company (about 60 employees, including 12 people employed in the design office) realizing the model of unit production.

Guillotine cutting is very often used in this industry. It is a waste-free, efficient processing method, the cutting tools have a long service life, and their inspection and maintenance are relatively inexpensive.

This chapter describes the evolution of technical solutions used in the construction of cutting devices for sheet metal and profiles made of sheet metal, which have been used since the 1990s to the present day in this company. The description also refers to the development of supporting tools used in design processes during this period. Due to the multitude and variety of types of processes and cutting equipment, the company has a lot of such equipment designed and manufactured over the years. Figure 1 shows some of the more interesting shapes for which the cutting equipment was built.

The case description consists of two parts. The initial one chronologically presents some of the key projects that had a significant impact on the directions of development of subsequent devices of this type. In the next part there is a reference to the design tools used, as well as a generalisation of the observed phenomena and an attempt to assign the knowledge and tools modelled there to particular levels (I, II or III level) mentioned in the introduction. A description of various external factors relevant to the project work was also added, as well as descriptions of events of significant importance. The material used for the analyses came from the sum of accounts of persons participating in engineering works.

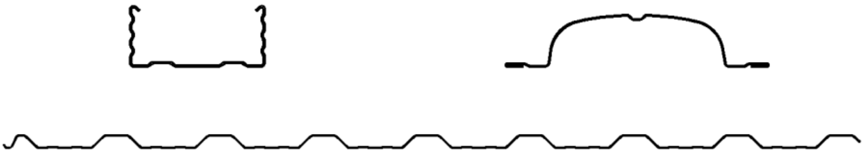


Figure 1. Sample shapes of guillotine cut details.

2. Historical background to the development of guillotine devices - evolution of conceptual solutions

This chapter presents the process of evolution of specific, conceptual design solutions in a historical perspective [21-24]. The beginning of the presented deliberations is the first half of the 1990s. In that period the company produced only simple hydraulic guillotines for cutting flat sheets. An outline of two types of such devices is presented in Figure 2 design case A. At this stage of development only basic calculation methods were used. Some knowledge of technological conditions was also used. At that time, the group of constructors consisted of only 2 people, and the transfer of knowledge took place through direct exchange of thoughts and the joint development of issues.

In the mid-1990s there was a need for guillotines for cutting trapezoidal sheets. In the case of trapezoidal sheets, the geometry of the cutting knives was problematic. The direct adaptation of the cutting principles (inclination of the movable knife by about 2 degrees) of flat sheets proved to be a failure. At that stage the only intuitively correct solution seemed to be to cut off this type of product "at once" without using step cutting. However, this would have resulted in a very significant increase in cutting force, so large that building such a device would not make economic sense. This forced designers to look for another solution. Finally, after many tests and trials, it was possible to develop a knife geometry that allowed good cutting quality with the required cutting force that was at an acceptable level. Figure 2 design case B gives an overview of the shape of the designed knives for trapezoidal and flat sheet metal cutting.

Another noteworthy modification of the guillotine type devices in the presented company took place in 2005. At that time, the first ever guillotine driven by a gearbox with an electric motor (instead of a hydraulic cylinder) was designed and built. The factors that made it possible were a significant (compared to the situation in the mid-1990s) drop in the prices of electric drives, as well as the significant dissemination of this technology, which resulted in the fact that the company's automation engineers were able to design and build appropriate power supply systems. Another advantage of such a solution is that it does not require servicing and maintenance, which is necessary in the case of hydraulic systems. Figure 2 design case C shows an illustrative sketch of the construction of the guillotine for cutting trapezoidal or flat sheets with the electric drive.

In 2010, the company built the first profile cutting guillotine, which can be qualified as two and a half dimensions. This concept is based on the fact that the roll formed section in two dimensions was cut in a shape other than straight. Figure 2 design case D shows the construction of such a guillotine.

The next stage in the development of sheet metal cutting technology was the introduction of devices called “flying” guillotines. This is a solution that allows the cutting off of the material (in our case steel sheets and sections) without stopping the device. The main advantage of this method is a significant increase in the efficiency of the production line because time is not wasted on stopping it and starting again with each cutting cycle. The first realization of the device with this feature took place in 2011. As for the construction, a typical guillotine is mounted on a moving trolley which synchronizes its speed with the speed of the production line. During this time, the cutting takes place. Then the trolley returns to its base position and waits for the next cutting operation. The development of this technology was made possible by further increasing the competence of the automation department, purchasing new machining centres, and developing the knowledge of the design department. Figure 2 design case E shows a conventional and “flying” guillotine for cutting sheet metal.

In 2012, the company received an order to build a machine that would be able to cut corners and holes on flat sheets. In order to meet this challenge, a machine was built that used concepts previously developed for guillotines to cut flat sheets. They were developed with modules for punching out corners and holes. Quite an important innovation was to build software that was able to automatically create machine code directly from flat drawings in the *.dxf format. Figure 2 design case F shows this type of machine.

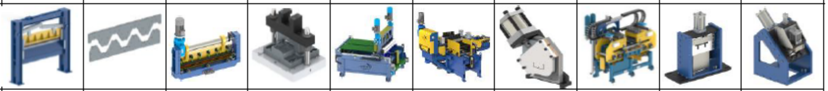
The development of “flying” guillotine technology has opened up the possibility of supplying machines for profile production of so-called "dry wall sections". The requirements for these machines are very high performance and high reliability. In the course of such a task (in 2015) a technology was additionally developed that allowed for waste-free cutting. Figure 2 design case G shows a guillotine for cutting this type of product.

In 2018, the concept for a machine for cutting, and punching out corners and holes with the possibility of punching out similar shapes in a roll formed section was developed. Figure 2 design case H shows such machine.

Another challenge in 2018 was to cut, using a guillotine, a section that had vertical walls quite close together. Although its shape is similar to the shape of trapezoidal sheets, in this case it was not possible to apply the rules and knowledge of these issues due to the fact that the walls were parallel to each other, and this breaks all the rules of staged cutting (mentioned in the section above concerning trapezoidal sheet cutting). After a series of attempts, the assumed results were achieved. During these tests, new, very valuable knowledge on this type of cutting was acquired. Cutting these types of profiles is always done with saws or circular cutters. Figure 2 design case I shows the device for cutting it.

In 2019, the concept for the device discussed above was extended upon request. This time, the parallel-wall profiles were cut at an angle of 45 degrees. Figure 2 design case J shows this device, and also a section cut at an angle of 45 degrees.

Figure 2 shows all the issues discussed above and their position in the timeline. In the next part of the article they will be discussed in more detail in terms of the sources of knowledge used and the techniques of processing.

Design Case	A	B	C	D	E	F	G	H	I	J
Example sketch										
Guillotines design development stage/progress	*Flat sheet hydraulic drive*	*Trapezoidal sheet hydraulic drive*	*Electric drive*	*2.5D cutting*	*"Flying" shear technology*	*Flat sheet notching and non-straight cutting*	*Paralel wall section cutting*	*Rollformed sheet notching and non-straight cutting*	*Paralel non-scces wall section cutting*	*3D cutting*
Year	1990	1995	2005	2010	2011	2012	2015	2018	2018	2019
Knowledge processing level	level 1 (nonformal) → 1		level 1 (formal) → 5			level 2 → 6		level 3 → 9		
Milestones (from the point of view of knowledge for guilotine development)	Basic cutting function	Shaped, flat baldes geometry	Calculations and rules for electric drive and mechanical components	2.5D blades geometry	Calculations and rules for electric drive and mechanical components	Processing not straight cuts. Automatic generation code form _.dxf files	Hi-performance specific sections waste-free cutting	Combination of roll forming and cutting process	Intentional deformation of one end during the perpendicular cutting process	Intentional deformation of one end during the cutting process at any angle
Knowledge processing tools and accompanying phenomena	Basic calculation methods Technological restricitons Difficulties in knowledge sharing, storing and reusing Non-formalised experiments 2D CAD tools Lack of formal structures		First formal represenatations First validation methods Formalised experiments Detailed reporting 3D CAD software Multimedia techniques for knowldege stroring Duplication of mistakes and work already done Problems with finding desired content in company resources			Idea of design templates KBE - mostly initial estimations Author's design supporting application CBR techniques CAM software Ease of reusing previously gathered knowledge Macros for CAD and CAM software		CBR techniques Formalised validation of gathered resources and templates Company's knowledge repository Tracebility of design versions Wizards for quick design of standard components		
Development influencing factors (compared to the previous period)			Increase in level of designers' qualifications Increasing the number of design teams Extension of machining possibilities (new machines) Purchase of new types of software Cooperation with external partners (companies)			Increase in the level of automation engineers' qualifications Dissemination of electric drives technology Cooperation with foreign experts		Increased level of size and complexity of design tasks Expanding the company's product range Further extension of machining possibilities (new machines) Creation of a company research and development centre for sheet metal profiles		

Contributing reasons for the development factors:

- market demands for better and more efficient production lines — 40%
- obtaining an EU grant for the expansion of the company — 60%

Characteristic features for knowledge processing:

- problems with transferring and sharing knowledge to new members of the design team
- "new look" at the problems encountered by inexperienced designers
- first attempts to formalize the knowledge processing processes
- gradual increase of competence of project team members in the context of using the company's computer tools and knowledge processing methods
- no formal procedures to assess the quality of created solutions
- incomplete use of the company's computer tools for design support

Contributing reasons for the development factors:

- further market demands for better and more efficient production lines — 20%
- design and construction of much more complex and complicated production lines — 60%
- further development of cooperation with external domestic and foreign experts and companies — 20%

Characteristic features for knowledge processing:

- development of tools created in previous periods and implementation of new more advanced tools
- significant increase in the use of advanced functionality computer tools (commercial and company-created computer tools)
- significant part of the design team have mastered the knowledge at an expert level
- processes for assessing solutions and tools supporting design were implemented

Figure 2. Evolution of metal cutting machines development.

3. Tools for knowledge processing and management - historical background

The beginning of the presented deliberations is the first half of the 1990s. In that period the company produced only simple guillotines. Due to this, as well as the small size of the design team, only informal procedures and calculation methods related to them functioned then. Often, not entirely rational reasons for design decisions were taken into account. The main and, in principle, the only source of knowledge, was the design documentation and quite sporadic records of the calculations carried out. Despite the fact that the team of designers at that time consisted of up to three people, there were significant difficulties in sharing knowledge. The phenomenon of pointless and thoughtless duplication of some activities could be observed. There was also a lack of evaluation of newly designed solutions, which in consequence led to the creation of new solutions containing the same errors that occurred in earlier implementations. In the available resources it was usually impossible to find the premises that were behind the choice of specific solutions, which of course made the process of reuse, or use with changes of one of the old solutions much more difficult. Despite the lack of any formal structures, knowledge was partly preserved, partly verified and partly validated. However, these activities were usually carried out only mentally, separately by each of the designers. Taking this into account, the activities and methods from that period can be qualified as non-formalised level I tools.

This state of affairs lasted until the second half of the 2000-2010 period. One of the factors leading to change was that new people with relatively little professional experience joined the team during this period. Due to the fact that the knowledge resources were in no way formalised, the implementation of new employees to work in the team was very slow and hard. This fact highlighted the need to consolidate and manage certain knowledge resources. Initially, these were primarily resources containing formal, textbook knowledge, which were made available online. Over time, the system was developed with very simple validation tools. These were extensive collections of notes, films and photographs where both problems and their solutions that occurred during the manufacture, assembly, commissioning or operation of a given device were recorded. These activities were of a bottom-up nature. In the initial phase they were not fully implemented in a planned and conscious manner. From today's perspective it is also group I.

The next step is already targeted actions from 2012 [3, 4]. At this stage, some of the processes were already formalised. Many times, it was possible to use them or their parts for activities other than those for which they were created. A concept of templates was created, which conceptually was related to specific classes of project activities. This formalism was intensively developed towards integrating both informal and formal representations into a single template. Appropriate classes for each of these two cases have been identified. The versionality of the templates was introduced, as well as the monitoring of their use cases and planned future use cases. Elements of investment policy were added in this area. Each of the above-mentioned variants could be created as an effect of real engineering processes. It could also be an effect of the reflection of individual designers or the discussions of several designers. All these elements were properly recorded and commented on. These solutions represent level II.

Around 2015, experiments with CBR (Case Based Reasoning) class solutions were initiated [17, 18]. It was primarily that in levels I and II a fairly large set of different representations was used. It became necessary to create level III so that a uniform representation could be applied to the CBR method. Figure 2 presents the development of cutting equipment design with the assignment of their subsequent stages to specific classes of knowledge modelling tools.

Another element was various efficiency solutions related to the use of CAD/CAE systems. Far-reaching specialization is progressing in many real-world processes. Consequently, the used tools, including computer tools, are subjected to this process. CAD / CAE class systems may turn out not to be often needed in their entirety; only some of their functions are needed, almost in the form of a dedicated service. The way engineers/designers define a problem is also changing - a more advanced division into human-defined components (expressing his ideas - creative actions) and automatically implemented components that are easy for a computer to interpret and proceed is possible.

An example of such a solution [25] can be a system which is used to support the frame design process of certain selected types of machines. Defining the structure and parameters of the frame is done by the designer using the 3D wire modelling editor. Next, the obtained model is supplemented, also by the designer, with icons that define the cross-section forms and connections of individual frame elements. Then the basic information, necessary to build FEM models of this frame, is entered (which is done by the designer). Further processing is already a typical automation. It involves the automatic construction of a detailed geometric model with the use of a CAD system, the automatic construction of the FEM model, and finally the automatically controlled analysis of this model. Work with this application resembles the cooperation between a designer and an assistant, where the human defines the basic components of the design task. Of course, the designer usually has more such highly specialized tools at hand.

In addition, the analysed processes widely took into account other elements, apart from the substantive side of design processes and knowledge-based support tools. The main factors are presented in Figure 2. In addition, the same picture shows two selected events, crucial for the functioning of the company, with their background in terms of knowledge, decisions and other elements. In the picture, each event is linked by lines to specific elements affecting it. The degree of importance of this influence for the whole event is shown by a dimensionless indicator from the range 1-10 (10 - maximum influence). The values of this indicator are the averaged values given by persons reporting on the studied processes.

4. Conclusions

In conclusion, we can say that the use of knowledge-based tools in product design and development processes has several contexts of tools based on different representation levels of the modelled knowledge (levels I, II, III) [3, 4, 26, 27]. An equally important context is the dedicated KBE tool. All of these 4 elements (three levels and the KBE tool) constitute a whole system connected with many dynamic relations. For example, knowledge acquired and stored at levels I and II becomes the basis for building dedicated KBE tools. Experience in using KBE tools becomes the basis for articulating knowledge at levels I and II, etc.

An equally important issue, in the case of the analysis of real project tasks, is the substantive side of the project, the level of its complexity, and the whole set of various additional factors, the impact of which is crucial for the functioning of the whole. The analysis made by the authors, fragments of which are included in the paper, has shown that the success of methods supporting knowledge-based design is determined by quite a number of elements that occur in the so-called broader context of the analysed engineering processes [15, 18, 24, 30].

The created whole provides not only the possibility of short-term management of engineering knowledge, but also, in the long run, allows for the analysis of the evolution process of design methods used in a given company [22]. This may constitute a basis for the application of approaches of a more strategic dimension.
The adopted solutions also assume a very important personal/team aspect of the modelled engineering knowledge [3, 4, 18, 28, 29, 30].

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An Approach for Agile Engineering Change Management Within Global Product Development

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Abstract. Engineering Change Management (ECM) is an essential constituent of any product development project, these project are highly dynamic process of knowledge generation and reuse for products, projects, processes and resources within a enterprise. Currently, ECM is fully document-, and at least partially paper-based, and needs to be transformed to a fully model-based standard workflow. Changes, uncertainty and hidden processes should be seen as regular events. For the agile process, a rapid and flexible handling of task items is necessary. Due to the unpredictable character and short time of singular task items, we have developed a new approach to collect all changes to a superordinate, master change note as a standard, common object in the product structure, and to and update this master change note as often as necessary. This change note is assigned to a product during its entire lifecycle. It collects changes in the product and related processes and equipment. We present a new approach in order to facilitate a full object-oriented support of all activities related to the change process. On each update, singular task items can be re-prioritized within this master change note according to the current needs.

Keywords. Engineering Change Management, Agile Process, Global Product Development, Product Lifecycle Management

Introduction

The design process rarely starts from scratch, but rather by customization or modification of existing products during multiple optimization loops. An Engineering Change (EC) is an alteration made to parts, drawings or software, and it comprises any modification to the form, fit and/or function of the product as a whole or in part. Engineering Change Management (ECM) is an essential constituent of any product development project which is a dynamic process of knowledge generation and reuse for products, projects, processes and resources within a enterprise [1]. The increasing complexity of products, shortening of time-to-market, and growing dependencies on suppliers increase the number and complexity of change requests in all phases of product development. Today, developments project in the industry need a strong support of the EC process to meet

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the goals in terms of time, costs and quality. Appropriate anticipation, detection, follow-up, and resolution of engineering changes is paramount to project success [2].

The complexity of ECM is substantially impacted by two factors. At the one hand, global product development multiplies the count of interdependencies in the design process. On the other hand, coping with the recent trends in business and society, agile approaches have penetrated in almost all engineering and management disciplines in recent years.

Globalization of product development not only offers great opportunities in terms of flexibility and cost savings, but also creates new challenges due to the diversity of requirements in different contexts (such as countries, organisations and situations), and in particular regarding regulatory requirements (e.g. in the medical devices industry). Some obvious reasons for requirements diversity for a given product in different contexts are historical, cultural, natural, and economical [3].

Agility as a basic process capability is increasingly important because changes occur in our world continuously and uncontrollably, and the direction of the development of the business environment (i.e. trends, politics, customer, and project partner) is unpredictable. To cope with the connected challenges in the area of product development, companies try to transfer and integrate agile development methods from software product development to the mechatronic product development domain [4].

The remainder of this paper is structured as follows: Section 1 provides an insight into literature review, followed by section 2 where the need for action is presented. Our new concept is described in section 3. We discuss the advantages and drawbacks of our conceptual solution in section 4, followed by conslusions and outlook in section 5.

1. Literature review

Clarkson et al. have provided an overview of EC. They describe the nature of the engineering change as a basic engineering process, which combines the procedural handling of design errors with the subtler and/or more substantial resolution of issues arising from uncertainties in designer, customer and market requirements [5]. Classification of EC according to different criteria (cause, initiator, impact etc) is presented. Several stand-alone tools to support both workflow and decision-making in ECM have been described. In addition, the authors discuss how EC is connected to the makeup of the product in terms of architecture, complexity and degree of innovation. Finally, they outlined management strategies to deal with the issue of engineering change.

Knowledge management (KM) in the engineering change (EC) management process is crucial for any manufacturing enterprise [6]. Systematically gathered, analysed, and interpreted professional experiences can prevent technical problems, unnecessary costs, and unnecessary delays. Successful implementation of KM requires a holistic and transdisciplinary approach. The main contribution of the paper is the five-step KM model that is integrated into the EC process. Failure modes and effects analysis (FMEA) and design history files are the documents used to manage the knowledge related to a specific product. A product's design history file should contain explanations of decisions. Supporting activity for applying KM includes a campaign to raise awareness, and the transfer of tacit knowledge should be emphasized. This can be stimulated by mixed teams of senior and junior engineers. The content of the acquired knowledge should be checked periodically, and the analysis should be followed by corrective measures.

As the US Federal Aviation Administration (FAA) modernises its legacy air traffic systems by 2025, traditional systems engineering practices need to be transformed to efficiently and effectively address tomorrow's demands [7]. Agile practices in the commercial and federal domains have proven that it is a valid method to deliver high quality products in alignment with users' needs. An agile systems engineering approach moves away from a traditional development timeline (design to deployment) of about 7.5 years, and capitalizes on opportunities to expedite the delivery of operational capabilities that have been tested, integrated, and are of value to the end user. An agile design methodology is based on the idea of an agile development process, where design flexibility facilitates the ability to rapidly adapt operational and technical changes. Both agile frameworks attempt to minimize risk through the continuous delivery of incremental value to the user community, where the system addresses a set of critical operational needs based on user's prioritization input within a fixed timeframe and a budget-constrained environment [7].

With agile, the systems engineer, developers, and aviation community stakeholders, including air traffic controllers, airline carriers, and technical standards committees, must work efficiently within the available resources, including time and money. Agile focuses on the high priority operational needs so that the design may evolve, and ensures that the system's objectives are aligned with the stakeholders' needs and goals. An agile approach enables the FAA's systems engineers and software developers to continuously refine the technical scope based on cost and schedule constraints and operational and technical changes, and to define an implementation plan that drives the delivery of usable features for NextGen systems to the aviation community [7].

Agility in product development can be enabled through an adaptive engineering change management concept. Hence, the three categories are proposed as design elements and are described hereinafter as layers: Adequate means of communication form the front-end of the framework, processes and roles the intermediate layer, and a suitable data structure the back-end. For a suitable design of the means of communication, content-related data must be accessible at any time, standards for documentation must be provided, and shop floor staff must be supported in communication processes. For processes to be efficient, they have to be customised accordingly and a clear scope of duties must be assigned to members of the organisation. In order to guarantee error-free data management, geometric data have to be digitalised and application systems must share common data structures [8].

Scrum's agile techniques were also examined for use in the engineering of machinery and plant construction, since the entire Scrum process does not always have to be established in industrial practice of manufacturing physical products. Subsequently, the methodology for agile engineering in mechanical and plant engineering was developed, which consists of a reference model, a scaling method and a software tool. The reference model shows the current state of the art and research in relation to mechatronic development processes using agile techniques. Using the scaling method, the reference model can be applied with regard to the agile techniques to be used as well as the activities of the mechatronic development process and a suitable agility class can be concluded using context criteria [9].

A survey shows that the participants from industry have a high demand to make their development processes more agile [10]. Most of the non-agile users are afraid of the implementation challenges and that not enough support is available. These challenges should be eliminated to make it easier for the non-agile user to implement agile development. An overview of agile methods and selection process would be particularly helpful [10]. Implementing agile development would address certain challenges, such as the overhead of managing requirements changes, currently impacting non-agile develoment. In the implementation process, it is important to change the company culture and the mindset of the employees as well. This underlines that a structured implementation of the agile development is very important.

The suggested implementation methods (method overview, selection method, adaption method, planning method) and a guideline are perceived as being helpful. However, their application has to be supported by coaches or persons who have experience with agile development. In contrast to the standard Scrum procedure for managing changes, our proposed approach regards the development situation at the time of an ECR. However, the simplicity of the workflow proposed, comparing it to existing ECM approaches, enables to easily integrate it into an agile framework. Furthermore, the workflow for managing Engineering Changes within an Agile Framework provides decision support for evaluating the change request's implications on the ongoing sprint. This is illustrated in the presented case study [10].

Nevertheless, it is suggested to proactively manage changes by scheduling short sprint durations at the beginning of the development process, and by deriving highly specific tasks from the product backlog. Consequently, significant errors will be detected earlier and the change effort remains low [11].

Product generation engineering is understood as the development of products based on reference products (precursor or competitor products). Subsystems are either adapted to the new product generation by means of carryover or they are newly developed based on shape variation or principle variation. Continuous validation is considered as the central activity in the product engineering process and is a major challenge, especially for complex mechatronic systems. By using a new validation approach product engineering was transformed to agile and a significant progress beyond the V-model was achieved [12].

Nevertheless, the introduction of agile methods in product development opens or multiplies a handfull of other callenges like work coordination [13], conflicts by change [14], design trade-offs [15], visualization of work progress [16], modular design [17], supplier integration or intellectual property protection [18] which need to be properly tackled. Therefore, the agile transformation has a paramount impact to product devlopment.

Future research will examine whether the proposed approach provides sufficient documentation of engineering changes, when adding and removing requirements to and from the product backlog [11]. This is especially relevant for companies such as automotive suppliers or medical device manufacturers, that are required to comply with norms for documenting their engineering changes (e.g. DIN 199-4). Moreover, the workflow should be further evaluated by implementing it in a broader selection of startups that use agile project management methodologies.

There are further studies on agile product development. However, no method is known at this time which handle ECM as a specific process in the agile process. The CAx tool chain also must be adapted accordingly [19]. Through the early use of simulation software, a simulation-driven development process is targeted, wherein designers and engineers create a basis for joint developments and thus a basis for discussion, suggestions and new ideas. Adjacent methods and applications can be integrated in such an approach [20].

2. Need for action

In comparison with other business processes, e.g. sales, purchase or finance, managing engineering processes is even more challenging because engineering changes can be long-running tasks. During this time period many things may change – what has begun as a modern, adequate requirements with correct means, can become obsolete because it includes evolved requirements when reaching the planned deadline. Based on their mixture of creative tasks, collaborative work and repeating activities, engineering processes need to handle a high level of inherent uncertainty. This results in very complex processes with many alternative paths and sections that cannot be planned in advance [21].

Business process modeling (BPM) systems have been developed based on a mind model as process chains or task chains. Changes, uncertainty, and hidden processes are seen as exceptions instead as regular events. Adequate support for engineering processes in terms of modeling and execution obviously requires a completely new approach for process management that is able to deal with the requirements for flexibility, transparency, and efficiency, both in design and execution of the process [21].

A modelling approach to enable agile processes has to support the design of huge, complex processes, by using modularity but also allowing for an overall picture of the process, decrease the effort for changing and maintaining the process model, and allow agility and flexibility not only in process modelling but also in process execution through software systems. A goal- and context-oriented business process modelling provides a solution using:

- A modular process model that describes the single steps of a process (sub-processes, activities) separate from the goals of the process and the different contexts in which the process can be executed;
- different modelling levels, for the different parts of the process model; and
- a seamless "translation" of the process model into process execution.

This modular, goal- and context-based process model can then be directly executed as an agile process, by considering current goal and context when determining the next step in the process. In our case, as a medical device manufacturer is moving into an agile development not only for software products, it is necessary to be able to support agile projects without compromising the compliance requirements and documentation. In the past, Change Management project have delivered lessons learned that the Change Management process needs to be examined and made with the following goals:

- Using the current CM system adhering to the standards
- Supports agile product and process development and improvements
- Support flexibility in scope and timing of change activities
- Leverage baselines, Change Note (CN) revision and CN reuse
- Use the current organizational structure and competences
- Incorporate recommendations and industry best practices

Such a complex process must be implemented by using a modern PDM system. While ECM is a standard process, the implementation of the agile ECM should be provided by using adequate PDM objects [22]. The central function in this chain should take the Engineering Change Note (ECN). The change loops should be decomposed according to the agile process e.g. Scrum. The adopted process could drastically reduce or remove the need for so called emergent changes (which need to be done within a day).

3. Solution concept

Following to the overall concept of PLM [23], the demand is given last but not least by regulatory rules. For our purpose, a solution which continuously maintains the relationship between the current product configuration, and the different phases of the EC process, (the engineering change request (ECR), the engineering change order (ECO) and ECN) is necessary. A specific PLM object within ECM should make ECM an integrated, value-adding component of product development. Complete product with all variants and instances lies in focus - with no gap in the timeline between the first idea and disposal. A market study has discovered that no PLM system has a straightforward solution to support the needed ECN flexiblity, neverheless PLM systems posses the potential to be configured to support it. Therefore, a proprietary solution based on a standard tool set must be drawn and implemented. It includes the following characteristics:

- Document (with transparency) product changes
- One model that fits software and non-software development
- Better monitoring of change activities
- Interfacing with project and cost management
- Support : Change Faster & Document Better (CF&DB) approach

An ECM based tool must be available for change coordinators at the desired time and provide functionality for the entire product as well as each extent of the product structure (e.g. specific variant). By embedding this workflow into PDM system, it will be avaiable for all users in a global development network [24].

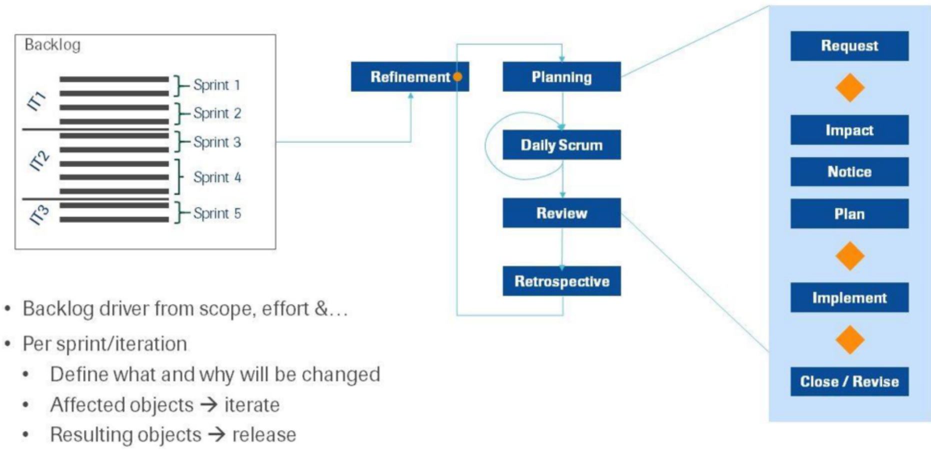

Figure 1. Engineering Change Management in Scrum.

While the authoring systems (MCAD, ECAD etc) are tightly coupled with PDM systems, the Engineering Change Management (ECM) is included into PDM as a basic workflow which includes all authoring and administrative steps [25]. Figure 1 shows the main constituents of ECM in Scrum. First of all, the product backlog is the driver based on scope, effort, estimated time, priority, etc. Singular tasks are assigned to sprints and iterations which can be reordered according to the actual needs. For each sprint or iteration must be defined what will be changed and why, the affected product objects which will be affected during one or more interations and resulting object which will be subject of release.

In our case, we consider a simple assembly consisting of two half-balls which cover a ball inside as depicted in Figure 2. The considered change should be made by changing the ball radius. For that, the specification must be changed accordingly (affected object). At the product level, three parts must be changed (resulting objects) which must be finally released. By new ECM workflow, the PDM system provides the ECN object referenced to all impacted object (part, assemblies, processes, resources etc). This object is the central information carrier for all changes and is the subject of continuous release.

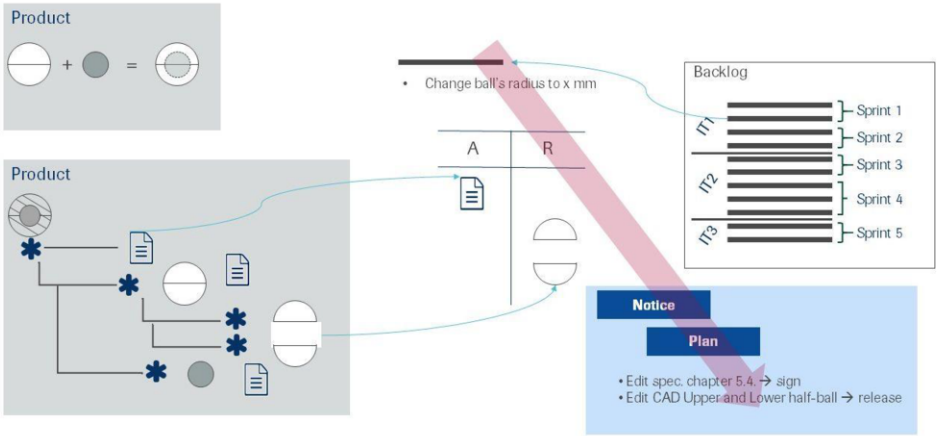

Figure 2. Affected vs. impacted objects.

The content of changes stays in the product backlog. Some objects will be updated some will be released according to the backlog.

The impact analysis phase is important for any change, as this determines the scope and, subsequently, the efforts and costs. It helps to understand the whole impact of a change and trigger activities related to the change (Figure 3).

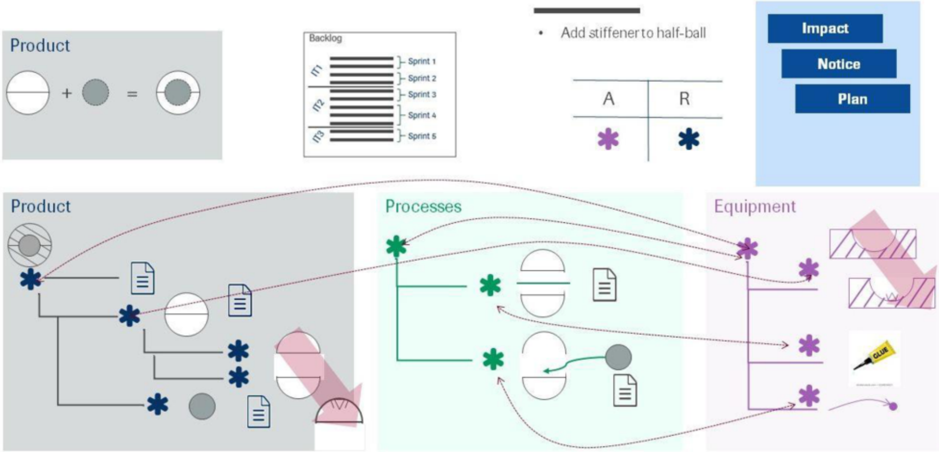

Figure 3. Impact analysis.

In our case, due to the extension of the radius, the production process must be adapted by adding stiffener to the half-ball used to manufacture the half-spheres. That imapcts the change of the production process and the related resources (equipment, jigs, additional materials).

The engineering change documentation process is depicted in Figure 4. Usually, engineers use decompositions to describe a product or process. In our case, a change request (CR) is an umbrella for all subsequent sub-processes and can be subdivided in more requests. The backlog is subdivided into iterations. Each iteration consists of 2-3 sprints. The implementation is stored in change notes (CN). This structure goes hand in hand with the agile process, documenting in increments and releasing according to the backlog plan: It allows the development to roll back changes in a documented manner, and the generation of baselines.

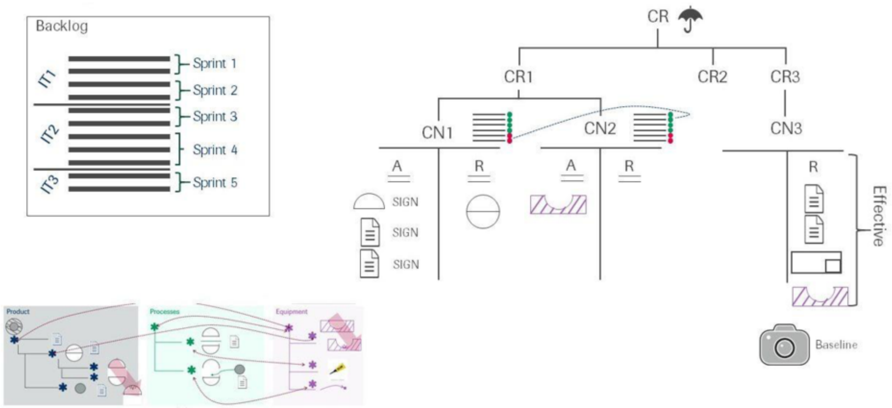

Figure 4. The engineering change documentation process.

Figure 5 shows the structure of the revision of change notes. While the singular action items can frequently move from a note to the another, it is necessary to define the rules and the process of update. We propose to build one change note object for each product item and maintain it during its lifecycle. This approach delivers flexibility in the creation and implementation of plan without losing traceability and transparency.

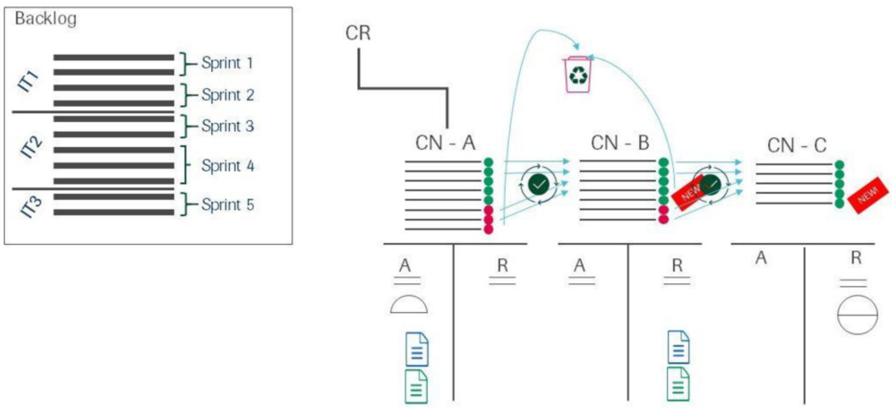

Figure 5. Revising change notices.

4. Discussion

The implementation and introduction of basic processes and workflows is challenging each company [14]. While the company is at the forefront of deploying practical applications of the PDM system PTC Windchill for a range of requirements, it is necessary to reconsider the existing workflows like ECM to fulfill the process requirements for the agile transformation [25]. Such workflows which affects the entire company bring the risk of failure or partial success with huge consequences. In our case, the primary risks are increasing complexity by additional processes/methods/tools, insufficient commitment of people and culture, and, finally, delayed replication of a globally working organization to every local situation. These challenges need to be tackled by a proper project organisation.

5. Conclusions and outlook

Agile engineering change management embedded into PLM is a pre-requisite in order to realise efficiency gains and not add additional cost within global product development. [26]. Current PLM systems ,which are built to support linear change management can be adapted to support agile product development. The artifacts of the EC process in PLM, namely the ECR and ECN can be used to match product backlogs including priorities and assignment to increments. To support this a two-tiered level of release has to be enabled in the PLM system to allow design obejcts to be finally released or flexibiliy incrementally approved until a final realease is reached.

In daily management, it is natural to define and decompose goals, define, reuse or refine plans, and continuously monitor and check the execution of chosen plans in order to detect problems as they occur, and to take appropriate actions. On the other hand, preferred IT approaches currently concentrate almost exhaustively on workflows based on procedures. The increase in process management automation that occurred with BPM systems has also shifted the focus away from goals and plans and toward procedures.

With this innovative approach, we have overcome the limiting consequence that processes have become more efficient in execution but less flexible in adaptation [27]. The desired result is given by achievement conditions to adapt the EC process to react to the variacnes implicit to the Agile methodology maintaining the needed documentation and transparency for both the enterprise and regulatory bodies. The possible ways to obtain a result are set by process graphs extended with the conditions where they are applicable and the results they obtain when successful.

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Challenges in Cost Modelling of Recycling Carbon Fiber Composites

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Abstract. The use of carbon fiber composites (CFCs) has become broad in many industries due to its superior properties compared to conventional materials. However, the increased demand coupled with environmental regulations has led to the development of different recycling methods for CFCs such as mechanical, thermal and chemical processes. Each recycling method has its own requirements and outputs along with some economic implications which need to be justified through cost modelling. This paper aims to identify current challenges associated with cost modelling of different processes for CFC recycling. The main challenges identified are grouped into three main categories such as technical issues, supply chain and market challenges.

Keywords. Cost Modelling, Carbon Fiber Composites, Recycling, Challenges.

Introduction

Composite materials find their application in a wide range of industries, such as construction, automotive and aerospace, because of their high strength, high stiffness, lower weight, as well as high thermal and chemical stability in inert conditions. Among different types of composites, carbon fiber composites (CFCs) are not exposed to stress corrosion or rupture at normal temperatures, which is typical for glass and organic polymers. They are appropriate for use in applications where strength, stiffness in pair with lower weight are the key requirements [1]. Hence, CFCs are extensively used in the aircraft industry due to their lightweight properties and actually contribute to the reduction of emissions from flights. Indeed, more than 50% of the weight of new aircraft such as the Airbus A350 is composed of CFCs [2]. Overall, the annual demand for CFCs was approximately 100 000 tons in 2019. The market of carbon composites is growing at a rate of 10-12% annually due to the increased usage of carbon fibers in aerospace, wind turbine blades and other applications [3]. The overall breakdown of CFC applications by market segments is illustrated in Figure 1.

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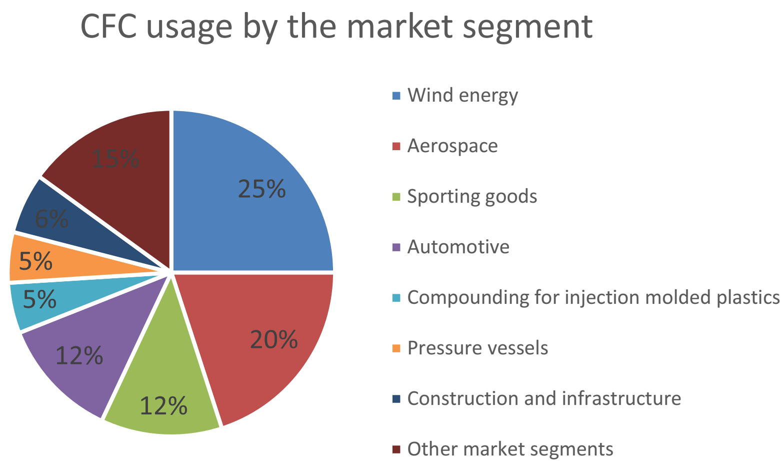

Figure 1. Breakdown of CFC application by the market segments [3]

Despite all the advantages CFCs offer, their increased usage has led to the generation of enormous amounts of CFC waste. It is stated that approximately 40% of all the composite material waste corresponds to manufacturing waste, and about 60% consists of woven trimmings [2]. The transportation industry accounts for almost 50% of the total amount, which creates a significant concern to create an environmentally and economically effective route for disposal of end-of-life products [4]. By 2025, 8500 planes with composite structures are going to be decommissioned, where each aircraft contribute 20 tons of CFC waste [5]. All of the waste products have to be managed with a minimum impact on the environment and maximum benefits for the producers.

For many years, landfilling was the only option for composite waste. However, from the End-Of-Life Vehicle Directive (Directive 2000/53/EC), the disposal requirements emerged: starting from 2015, recycling or reuse is obligatory for 85% of the weight of any end-of-life vehicle, and 10% of it for the energy recovery. Whereas, only 5% of the weight can be landfilled [6]. In other words, now vehicle manufacturers must consider recycling pathways for end-of-life vehicles, which in turn can be partially made from composite materials.

The industrial sectors that use CFCs are informed about legislation updates and uprising trends for sustainable green development. As now they are forced to recycle composite materials due to legislation, it is essential to estimate the costs of CFCs recycling for different methods of recycling. The data related to the recycling of composites is far scarcer compared to that of metallic components. Manufacturers do need to know about the cost drivers and the level of investment required to recycle such materials at the design stage. However, the development of cost models for CFC recycling faces some challenges and issues. This work aims to review those challenges associated with the cost modelling of CFCs recycling (mechanical, chemical and thermal treatments) by bringing a transdisciplinary perspective to the problem. Developing a cost model for composites recycling requires both a deep understanding of recycling processes and cost modelling techniques.

1. State of the art

The business is now as global as has never been before; hence, cost minimization is an essential key success factor in the market. It is important for companies to know the costs associated with CFC recycling processes for determining their success or failure. Both the manufacturing waste and end of life composites are usually disposed of using landfill or incineration. These disposal methods are not optimum, also environmental regulations have banned incineration and landfill of composites waste [7]. The best method to deal with such a challenge is recycling. According to Carberry [5], the manufacturing cost of recycled carbon fiber is 70% less as compared to virgin carbon fiber, also very less amount of energy is consumed for its manufacturing (98% less as compared to vCF). This encourages the recycling of composites.

Carbon fiber composites are difficult to recycle because: (i) thermosets are cross-linked and cannot be remelted and remoulded compared to thermoplastics; (ii) CFCs usually include inserts, cores, coatings, and removing these is time-consuming and difficult to automate and (iii) CFC composition vary extensively making the collection and separation of waste materials difficult [2]. Different methods available for the recovery of used CFCs are mechanical treatment, thermal treatment and chemical recycling, they are explained below.

Mechanical recycling is a conventional method of recycling during which several steps are carried out in order to cut and mill down the material to transform into short fibers (powder). Several companies applied mechanical recycling to thermosets, such as ERCOM in Germany and Phoenix in Canada [8]. Overall, the advantage of this process is that it does not involve any use of hazardous materials for both fibers and resins. However, there are many limitations associated with mechanical recycling. Firstly, the recycled product is either in the form of powder or short fibers, which extremely restricts the area of application of the secondary product. As a result of the quality of fibers, the mechanical properties of the recycled product allows to use them only as a filler reinforcement in new composites [2]. With the current prices for fillers such as calcium carbonate, the application of the recycled product as fillers can be questionable [8]. Secondly, the steps required to transform recyclate into powder are highly energy-intensive, which affects the financial viability of the process [9]. This may explain that ERCOM terminated its activity after 14 years due to financial problems.

The two main thermal methods (pyrolysis and fluidized bed recycling) are considered in this paper, as these are the only thermal methods which result in the recovery of the most valuable part of the composite – carbon fibers.

Pyrolysis is the thermal treatment of the material in the absence of oxygen. During pyrolysis, the temperature is heated up to 450 to 700 C, the matrix is decomposed into lower-weight molecules, while carbon fibers stay intact [2]. The variation of the mechanical properties degradation for pyrolysis is 4% to 20% compared to vCF [9]. However, the final properties of the product are highly dependent on the parameters used for the process. If the oxygen content and temperature are not controlled, the fiber properties can degrade remarkably due to pyrolytic char on the surface of fibers. [2]. Several attempts have been made to modify this method in order to eliminate pyrolytic char and preserve original properties. The methods are catalytic, vacuum and microwave pyrolysis processes. However, only microwave treatment and catalytic pyrolysis processes achieved the desired results with clean recovered fibers [9].

Overall, pyrolysis is the most widespread method to recycle CFCs in the industry. The technique does not involve any chemical solvents and is self-preserving in terms of energy by using gases to heat the chamber or produce the electricity [8]. Witik et al. [10] stated that pyrolysis requires only 5-10% of the energy required to produce vCF. A recent study by Guo et al. [11] demonstrated that recycled carbon fiber from the composite with epoxy resin had maintained comparable properties to vCF and can be used as short-cut rCFs in primary productions such as brake pads.

In the fluidized bed process, the size of the composite is reduced to be fed into a fluidized bed. The bed consists of silica sand of 0.85 mm in size. By fluidizing the sand with a stream of air at temperatures of 450-550 C° having velocity in the range of 0.5-1 m/s, the polymer matrix is vaporized, allowing fibers and fillers to be carried out in the gas stream. Then the fibers and fillers can be separated in a cyclone. Finally, fibers and fillers must be processed in a second chamber with a higher temperature (1000 C°) to fully recover the fibers [2, 10]. The advantage of this process is that it is tolerant for mixed and contaminated materials with metal inserts, which is the usual case for end-of-life vehicle components. Besides, the gases generated during the process can be used as a source of energy [8]. The resulting fibers do not show oxidation on the surface, hence, demonstrating good potential for bonding in a new polymer matrix. However, the mechanical properties of fibers are degraded up to 20% and their structure is damaged. The appropriate possibility to reuse products of this process are materials with short discontinuous fibers such as moulding compounds [4].

The chemical process for CFCs recycling is named as solvolysis and is further categorized as solvolysis at lower temperatures and solvolysis in supercritical fluids. Solvolysis at lower temperature utilizes reactive medium such as alcohol, or glycol to break down the polymer matrix structure. The process ends with fibers, other inorganic elements and excess solvent. Liu et al. [12] conducted an experiment on CFC by desolving it in nitric acid. The recycled fibers had only 1.1% loss in tensile energy. Compared to the methods discussed above, solvolysis at a lower temperature is efficient in terms of preserving the mechanical properties of fibers. However, the chemicals used in the process are hazardous and may have an environmental and health impact.

Solvolysis of CFCs in near or supercritical fluids has been developed for polymers in Japan since 1995 and is constantly being innovated. Supercritical fluid is any fluid which has temperature and pressure beyond its critical point with no distinct phase that allows its use as a solvent for industrial processes. Okajima et al. [13] was a pioneer in using supercritical water at 300-450 C° to recycle epoxy resin/carbon fiber. The results showed loss of tensile strength up to 10% for a single fiber. Jiang et al. [14] and Henry et al. [15] conducted experiments on carbon fiber reinforced epoxy resin using alcohol and a mixture of water and methanol, respectively. Both studies achieved reclamation of fibers with mechanical properties close to vCF.

Overall, the use of supercritical fluids has shown itself as an excellent option for recycling carbon fibers in polymer composites. However, it is necessary to investigate critical parameters of the process, such as type of fluid, temperature, pressure, time and type of a chamber used. Finally, solvolysis is very sensitive to contaminants in the waste. Hence, initial preparation and cleaning of the waste requires additional efforts.

From the review, it is clear that CFC recycling methods are evolving, each method has its drawbacks. The next section will group and discuss challenges related to cost modelling of processes for CFC recycling.

2. Issues and Challenges

Cost modelling of CFCs would provide a good understanding for manufacturers in deciding whether recycling or disposal of composites is financially viable. However, there are many technical and other types of challenges towards creating a practical cost modelling framework for different recycling methods. The main challenges related to cost modelling is related to identifying cost drivers – any part of the process which affects the final cost of a recycling process. For instance, direct cost drivers of mechanical recycling and pyrolysis, such as materials, machinery and labor are briefly discussed by Shehab et al. [16]. However, this type of data is not usually provided in detail by the researchers nor industry members and can be a possible obstacle in developing an effective cost model. In addition to the technical issues, other indirect challenges also have an influence on the cost modelling of CFCs. The challenges towards cost modelling of CFCs recycling processes are presented in Figure 2. The major issues and challenges consist of technical issues, supply chain and networking and market challenges, which are described further in detail in the following subsections.

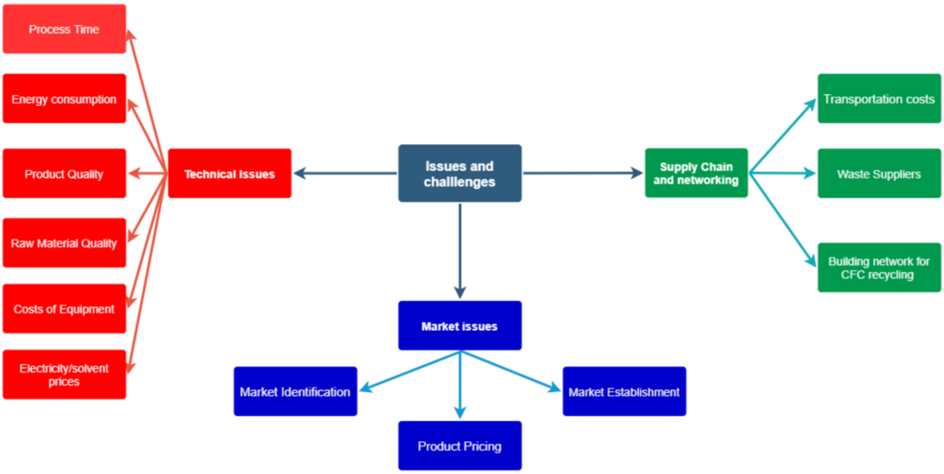

Figure 2. Challenges of CFC recycling.

2.1. Technical Issues

As it was discussed before, all CFC recycling processes have their own advantages and drawbacks. However, there are certain parameters that affect each of them in terms of cost modelling. For instance, energy consumption is one of the significant technical issues in recycling CFCs. It is essential that the energy spent on recycling CFC waste must be as low as possible since manufacturing vCF consumes 183-286 MJ/kg, which is 10 times higher compared with glass fiber [17]. It is a critical requirement for a recycling process to be energy-efficient. Hence, it is important to consider energy consumption in cost modelling for recycling CFCs. Taking into account that the data related to recycling composites is limited, identifying energy consumption rates for different recycling processes would be challenging.

Another obstacle for cost modelling of the recycling processes is the variety of raw material quality. Different end-of-life products and manufacturing waste have different types of polymers and contaminants, which create problems for separation and sorting. Hence, different materials require different levels of initial treatment before the primary process, which again may affect the costs of the process. The accuracy of cost modelling will definitely be affected by this issue if not properly treated. Developing a cost model that would consider the variations of raw material would be a challenging job.

The quality of recycled carbon fiber is dependent on the process selected and its parameters. It is a direct cost driver of the process, which defines the cost of the final product. As all methods have different output quality, it is a vital technical issue to maintain characteristics of rCFs comparable to vCFs.

There are other parameters that affect cost modelling of recycling CFs such as the equipment, electricity and components costs for recycling CFCs, which is unique for every process and location of the enterprise. Hence, it is essential to consider all parameters that may have an effect on the costs of recycling.

2.2. Supply chain and Networking

The first input for any recycling process is waste, hence, waste suppliers have to cooperate with recyclers supplying them regularly with waste in an appropriate form. The variation of suppliers and their reliability will have an effect on cost modelling of the recycling process. In general, building networks between CFC community members such as recyclers, suppliers and researchers is a critical challenge for the further development of the topic. It will define the quality, accuracy and relevance of the data, which is necessary to build effective cost models for CFC recycling.

In addition to that, as the recyclers and suppliers may be located at significant distances away from each other, transportation costs have a major influence on the final costs of the recycling process. It is necessary to continuously improve processes in terms of the supply chain and reduce overall costs. Effective cost models must take into account transportation costs before the recycling process is initiated.

2.3. Market Challenges

Recycled carbon fiber's application is limited due to its degraded mechanical characteristics and surface properties. Hence, the characteristics of different rCFs have to be known in order to label them and identify in which area they can be utilised [2]. Depending on the origin and final characteristics of the product, values for the recycled label can be assigned for the market. Product pricing will be another issue, as all the processing times and costs have to be adequately assessed. Lastly, the establishment of the market will be a major challenge. The key factor which predetermines the successful use of recycled carbon fiber is finding an appropriate use for the recycled products with their degraded properties. Up until now, this challenge has not been overcome and demand for rCF products in the market is still vague. The establishment of a market requires that all challenges discussed above have been overcome so that the general image of the rCFs should be robust enough to be reused as a cost-effective and environmentally friendly material.

Another concern related to cost modelling of CFCs recycling is that the industry members usually hesitate to disclose the details of their work, such as process parameters, recycled material properties, pricing, etc., to protect their competitive advantage in the market. This is an essential issue as cost modelling based on case studies conducted with companies would be more accurate compared to using data from the literature, which could be obsolete as time passes.

All the mentioned challenges in this section might have a significant effect on the reliability of results of the cost modelling framework. An effective cost model of recycling should include all the aspects discussed such as the technical parameters of the process, final prices of the recyclate, transportation costs, etc. For instance, Dong et al. [18] provided an economic model to assess the recovery pathways of carbon fiber. According to the authors, the unit costs of recovered carbon fiber were lower compared to the results of another research due to the limitation of the study, such as not considering the exogenous factors (type of waste, transportation, packaging, etc). This work highlights these factors in order to provide a robust cost modeling framework in the next stages of the project.

3. Conclusions

This work outlined the current state of CFC recycling industry and identified the main issues and challenges for the development of cost models of CFC recycling processes. Three main elements: Technical, Supply Chain and Market challenges are discussed in detail with their sub-elements.

It is found that there are many technical challenges associated with recycling CFC, such as energy consumption and variation of both raw materials and output recovered fibers. For the supply chain, dependence on waste suppliers and overall networking between CFC community members are highlighted. Finally, the current market for recycled carbon fiber is not established, which represents one of the key challenges in the success of CFC recycling.

This paper is a part of an ongoing project which aims to develop cost modelling methodologies for recycling and disposal of composite materials. In the future, identified key challenges could be a useful input in identifying cost drivers by providing a view on underlying factors that could affect costs. The next stage of the project is to develop a library of cost drivers and objects for cost estimation with the uncertainties and risks which could have an impact on them. By building case studies with industry members, eventually, cost modelling frameworks would be developed to predict recycling costs at the conceptual design stage.

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Modularity and Configuration Applied to Product Integrating the IoT Technology

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Abstract. The growth of the IoT (Internet of Things) offers a large number of opportunities for new product development. The adoption of IoT technologies improves the operational efficiency of products and their interaction with humans. The variety of sensors and communication protocols, the increased number of cloud infrastructures and services, not forgetting security challenges induced by the IoT technologies lead the designers to make complex choices in the configuration of an optimal IoT solution. Modularity and design for configuration represent an efficient solution for the design of products adopting the IoT technologies. This paper applies the model of configurable product design, conceptualized as multi-layer fuzzy models, to the product integrating the IoT technology. The layer models are the fuzzy product specification layer, the fuzzy functional network layer, the fuzzy physical layer, and the fuzzy constraint layer. The model discerns the consensual elementary solutions that create common ground for moving toward a global solution. The case study shows the configuration of a connected houseplant sensor.

Keywords. Design for configuration, modularity, configurable products, product modeling, multi-layer models, Internet of things

Introduction

The number of objects connected to the Internet, already far greater than the number of people online, is constantly growing. With 8.6 billion cellular IoT connections in 2018, estimates for 2022 are around 22.3 billion cellular IoT connections[2] according to the Ericsson Mobility Report (2019). This exponential growth in the Internet of Things (IoT) opens up an era of creating new services that can bring significant changes to society, the economy, and the environment, as well as a host of business opportunities. The adoption of IoT technologies in various fields such as smart cities, smart transportation, smart logistics, smart industry, smart metering, and smart grids improves their current operational efficiency of products and their interaction with the population [1][2][3].

However, the customers are no longer passive buyers of the products because they can participate in the customization of their goods prior to purchase. Companies that can provide customization and increased product variety improve customer satisfaction and achieve a significant competitive advantage. To face this societal challenge, the design

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[2] https://www.ericsson.com/en/mobility-report/reports - June 2019

of products adopting the IoT has to be optimized according to the dynamic and individual requirements of the customers. The variety of sensors and communication protocols, the increased number of cloud infrastructures and services, and of course security challenges induced by the IoT technologies lead designers to make complex choices in the configuration of an optimal IoT solution.

Modularity and design for configuration represent an efficient solution for the application of IoT technologies. Fodor revived the idea of the modularity of mind, although without the notion of precise physical localizability [4]. According to Fodor, modular cognitive systems fulfill certain criteria: (1) Domain specificity: modules only operate on certain kinds of inputs, (2) Informational encapsulation: modules need not refer to other psychological systems in order to operate, (3) Obligatory firing: modules process in a mandatory manner, (4) Fast speed: probably because modules are encapsulated and mandatory, (5) Shallow outputs: the output of modules is very simple, (6) Limited accessibility, (7) Characteristic ontogeny: there is a regularity of development, and (8) Fixed neural architecture.

These criteria are also valid in equal measures for modular technical systems [5] and intelligent systems integrating IoT technologies [6]. The main criteria for product modularity are component separability and component combinability [7]. These are coupled with other criteria such as commonality, function binding, interface standardization, and loose coupling [8][9][10][11][12][13].

Design for configurations uses the principles of modularity, as individual products are not developed anymore, only whole product families or product spectra [14]. Design for configuration is the design process, which integrates explicitly customer requirements and the services involved in the product realization process, such as manufacturing, assembly, maintainability, etc. to intelligently synthesize or generate the components, the modules, and the final product belonging to a virtual family of products [15][16][17][18].

Indeed, the product modeling process is characterized by several domains that participate simultaneously in the development of configurable products. Each domain has a particular view of the product. The design for the configuration process is also characterized by many degrees of freedom and possibilities due to the individualized requirements of the customers. Therefore, design for configuration takes into account: (a) the different views of the product, (b) the great number of product variants generated by the process, (c) the user-oriented characteristic of the configurable products, and (d) the possibilities and uncertainty of the design process. A fuzzy multilayer network of multiple fuzzy models, which correspond to the multiple views of a configurable product, allows an intelligent and adaptive way for product configuration [19].

Considering multiple views of the configurable product design, the fuzziness of handling imprecise design information and the modularity, a fuzzy multilayer network of multiple fuzzy models can be applied to the product configuration adopting the IoT technologies. In spite of some research that deals with the conflict resolution problem [20][21][22][23], there is a need to integrate methods that can reach consensual solutions during design configuration. The proposed approach uses the concept of consensus as the overlapping of customer perspectives and designer perspectives to converge toward a final solution.

The paper is organized into three sections. In the first section, the fuzzy multilayer network model for configuration is proposed. The second section presents the computing models for configuration. Finally, the third section describes a case study.

1. Fuzzy multilayer network model for configuration

The fuzzy multilayer model is composed of the following four interacting layers: the fuzzy product specification layer, the fuzzy functional network layer, the fuzzy physical solution layer, and the fuzzy constraint layer (Figure 1).

The fuzzy product requirement layer. A relationship exists between the set of product functions and the set of requirements, which indicates in what degree a requirement is accomplished by the set of functions. A fuzzy relationship can be defined between the set of functions and the set of requirements. The fuzzy relationship is characterized by the membership function, which takes values between 0 and 1.

The fuzzy functional network layer. The fuzzy functional network is used to represent the functional structure of a product. The functional structure of a product consists of functional elements and their interrelationships that involve decomposition and/or dependency. Usually the functional structure of a product is indicated by a crisp representation. In a functional network layer, the product functions are symbolized by nodes, and their relationships are symbolized by edges. Each edge is characterized by a membership function, which takes the value of 1 if there is a relation between the two considered functions, or the value of 0 if there is no relation.

Given the set of functions of a configurable product, it is considered that the relationships between the functions have different degrees of interaction. The variation of the degrees of interaction between the product functions leads to different functional configurations of the product. The degrees of interactions between functions can vary according to the functional configuration chosen by a user. So, different functional configurations can emerge during the design of the configurable product. To describe the interactions inside the fuzzy functional network, a fuzzy relationship is defined between each couple of product functions in the set of product functions. The fuzzy relationship is characterized by the membership function which takes values between 0 and 1, and represents the degree of interaction between each couple of functions.

The fuzzy physical solutions layer. Each function in the set of product functions corresponds to different product modules. Each module in turn has some alternative solutions. Each physical solution can satisfy the set of functions to a certain degree. This aspect implies that the relationship between the set of functions and the set of physical solutions has a fuzzy character. The fuzzy relationship defined between the set of functions and the set of solutions is characterized by the membership function. It takes values between 0 and 1 and denotes the satisfaction degree of a function by the set of physical solutions.

The fuzzy constraint layer. The integrated design is characterized by various activities that are involved in the process, where each activity has its own view of the product. The fuzzy constraint model defines the specific constraints of each activity that are integrated during the design process of the product. The existing process capabilities impose constraints on the product realization which reduce the number of possible product variants or configurations. The set of physical solutions must satisfy the set of constraints. So a fuzzy relationship exists between the set of solutions and the set of constraints, indicating that each physical solution satisfies the set of constraints to different degrees.

A fuzzy relationship is defined between the sets of constraints and the set of solutions. This relationship is characterized by a membership function that can take values between 0 and 1. The values indicate to what degree each physical solution satisfies the set of constraints.

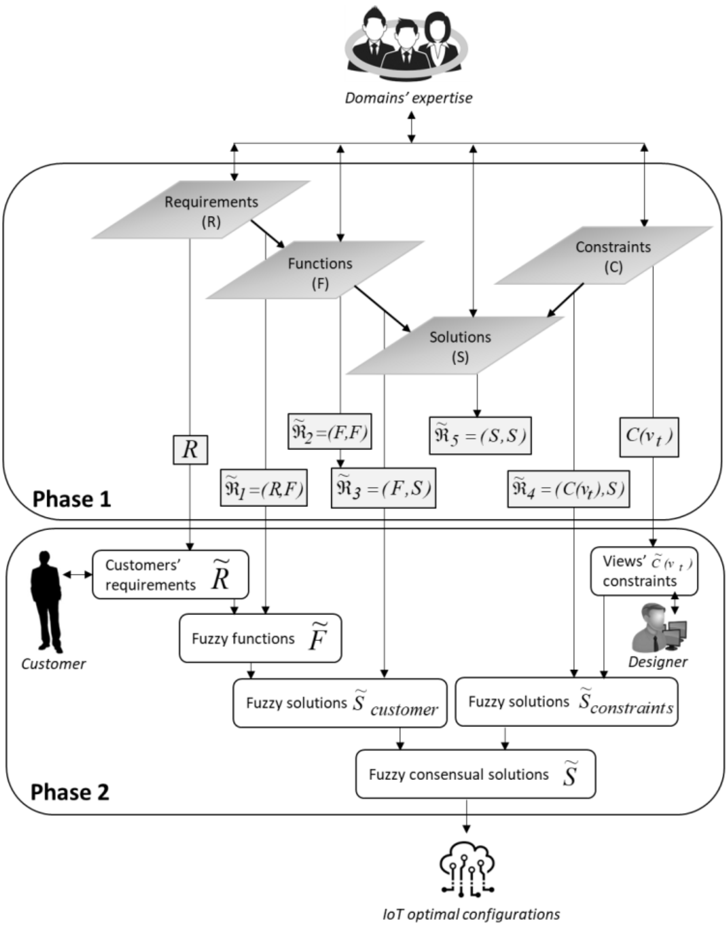

Figure 1. Fuzzy multilayer network model for IoT product configuration.

2. Configuration based on the fuzzy multilayer network model

Configuration starts with the definition of a requirement in the requirement domain. A customization requirement is manifested by the customer's choice of customizable requirements. The customer perceived value of each requirement indicates the degree of customer satisfaction in the requirement domain. Simultaneously, in the process domain, a constraint is manifested by the expert's choice of process constraints [15]. The expert's perceived value of each process constraint indicates the degree of expert satisfaction in the process domain.

Therefore, to satisfy customer requirements and process constraints, the mapping from the requirement to the solution, as well as the mapping from process constraints to the solution is applied. It yields a set of consensual solutions from both domains: requirement and process constraints. Then, this set of consensual solutions can be distributed in modules to form configurations [23].

Optimal configurations can be than generated using some limits of acceptability for objective function values. Limits of acceptability, whether communicated formally or established informally by experience, are familiar to engineers in the industry. It permits the early release of a possible set of configurations. Details for these phases are given below (Figure 1).

Phase 1: Building fuzzy relationships in product configuration. In this phase, different engineering design models, necessary for the configuration of a product, are built within and between domains. These models are expressed in the form of the fuzzy relationships. Table 1 shows the formal building of these fuzzy relationships and the meaning of associated membership functions.

In order to assess the membership functions, linguistic values are used. The following set is used to express the evaluation of actors: *E={e_0=worst, e_1=very poor, e_2=poor, e_3=fair, e_4=good, e_5=very good, e_6=excellent}*. Each actor chooses a linguistic value from the set *E* to express his/her evaluation. Table 2 represents the reference value as well as the interval-value for each linguistic value. In this way, the actors can assign a *degree of membership* or a *degree of belief* to each design parameter.

Table 1. Phase 1: Fuzzy relationships in product configuration.

Given

Four heterogeneous and distributed domains: (a) requirement, (b) functional, (c) solution, and (d) process constraint and their data consisting of:

1 Universal set of requirements $R=\{r_i\}$, $i \in I_R$, $I_R=\{1,2,\dots,n\}$; *these are customer requirements.*

2 Universal set of functions $F=\{f_i\}$ $i \in I_F$, $I_F=\{1,2,\dots,m\}$; *these are the functions of the product and they are designed to satisfy customer requirements.*

3 Universal set of solutions $S=\{s_i\}$ $i \in I_S$, $I_S=\{1,2,\dots,q\}$; *a solution is a designed physical object.*

4 Universal set of constraints $C(v_t)=\{c_{1t}, c_{2t},\dots c_{lt}\dots c_{r_t t}\}$ for the process view v_t , c_{lt} is the constraint number l for the view number t and r_t is the number of constraints for the view number t ; *A constraint is a restriction or a requirement of a view on any solution.*

Build

Fuzzy relationships in engineering design consisting of:

1 Fuzzy relationship between requirements and functions $\tilde{\Re}_1=(R,F)$.
Its membership function $\mu_{\tilde{\Re}_1}(r,f)$ *indicates to what degree a requirement can be accomplished by the universal set of functions.*

2 Fuzzy functional network model $\tilde{\Re}_2=(F,F)$.
Its membership function $\mu_{\tilde{\Re}_2}(r,f)$ *indicates the degrees of interaction between functions.*

3 Fuzzy relationship between functions and solutions $\tilde{\Re}_3=(F,S)$.
Its membership function $\mu_{\tilde{\Re}_3}(f,s)$ *indicates to what degree a function can be fulfilled by the universal set of solutions.*

4 Fuzzy relationship between constraints and solutions $\tilde{\Re}_4=(C(v_t),S)$.
Its membership function $\mu_{\tilde{\Re}_4}(c,s)$ *indicates to what degree a solution satisfies the universal set of constraints* $C(v_t)$ *for process view* v_t .

5 Fuzzy relationship between universal set of solutions $\tilde{\Re}_5=(S,S)$.
Its membership function indicates the degrees of affinity between solutions.

Table 2. Linguistic values.

Linguistic value	Reference value	Fuzzy interval
worst	0.05	(0, 0.15)
very poor	0.2	(0.1, 0.3)
poor	0.35	(0.2, 0.5)
fair	0.5	(0.3, 0.7)
good	0.65	(0.5, 0.8)
very good	0.8	(0.7, 0.9)
excellent	0.95	(0.85, 1.0)

Phase 2: Searching the fuzzy set of consensual solutions. In this phase, a designer, using the fuzzy relationships from Phase 1, customizes the product based on (a) customer perceived value of each requirement and (b) specific process domain constraints involved in its production, such as manufacturing, assembly, maintainability, and so on. Both particular customer's requirements and specific process domain constraints are fuzzy [15]. The result is a fuzzy set of alternative physical solutions, called fuzzy consensual solutions, which satisfy both customers' requirements and specific domains' constraints. The proposed model considers consensus as the overlapping of perspectives. The part or the fragment of a design solution which receives the maximum degree of consensus is called here consensus nucleus. Discerning the consensus nucleus as an overlapping of perspectives can help designers create common ground needed to move toward the final solution.Table 3 shows the formalization and different steps of this phase.

Table 3. Phase 2: Searching the fuzzy set of consensual solutions.

Given

1 Fuzzy set of customers perceived requirements $\tilde{R} = \{(r_i, \mu_{\tilde{R}}(r_i))\}$ over R

2 Fuzzy set of perceived constraints for process view v_t $\tilde{C}(v_t) = \left\{\left(c_{lt}, \mu_{\tilde{C}(v_t)}(c_{lt})\right)\right\}$ over $C(v_t)$

3 Fuzzy relationships in engineering design $\tilde{\Re}_1 = (R, F)$, $\tilde{\Re}_2 = (F, F)$, $\tilde{\Re}_3 = (F, S)$, $\tilde{\Re}_4 = (C(v_t), S)$

Find

1 Consensual fuzzy relationship between functions and solutions $\tilde{\Re}_3^C = (\tilde{\Re}_2, \tilde{\Re}_3)$ with membership function:

$$\mu_{\tilde{\Re}_3^C}(f,s) = \mu_{\tilde{\Re}_2 \circ \tilde{\Re}_3}(f,s) = \max_f \min[\mu(f,f), \mu(f,s)],\ \forall f \in F, \forall s \in S$$

2 Fuzzy set of functions $\tilde{F} = \{(f_i, \mu_{\tilde{F}}(f_i))\}$ over F with membership function:

$$\mu_{\tilde{F}}(f) = \mu_{\tilde{R} \circ \tilde{\Re}_1}(f) = \max_r \min\left[\mu_{\tilde{R}}(r), \mu_{\tilde{\Re}_1}(r,f)\right],\ \forall r \in R,\ \forall f \in F$$

3 Fuzzy set of solutions $\tilde{S}_{customer} = \left\{\left(s_i, \mu_{\tilde{S}_{customer}}(s_i)\right)\right\}$ over S satisfying customers perceived requirements, with membership function:

$$\mu_{\tilde{S}_{customer}}(s) = \mu_{\tilde{F} \circ \tilde{\Re}_3^C}(s) = \max_f \min\left[\mu_{\tilde{F}}(f), \mu_{\tilde{\Re}_3^C}(f,s)\right],\ \forall f \in F,\ \forall s \in S$$

4 Fuzzy set of solutions $\tilde{S}_{constraints}(v_t) = \left\{\left(s_i, \mu_{\tilde{S}_{constraints}(v_t)}(s_i)\right)\right\}$ over S satisfying perceived constraints for the process view v_t, with membership function:

$$\mu_{\tilde{S}_{constraints}(v_t)}(s) = \mu_{\tilde{C}(v_t)\circ\tilde{\Re}_4}(s) = \max_c \min\left[\mu_{\tilde{C}(v_t)}(c), \mu_{\tilde{\Re}_4}(c,s)\right] \ , \ \forall c \in C(v_t),\ \forall s \in S$$

5 Fuzzy sets of solutions $\tilde{S}_{constraints} = \left\{\left(s_i, \mu_{\tilde{S}_{constraints}}(s_i)\right)\right\}$ over S satisfying all fuzzy constraints $\tilde{C}(v_t)$, $t \in T$ with membership function:

$$\mu_{\tilde{S}_{constraints}}(s) = \min\left[\mu_{\tilde{S}_{constraint}(v_1)}(s), \cdots \mu_{\tilde{S}_{constraint}(v_t)}(s) \cdots \mu_{\tilde{S}_{constraint}(v_u)}(s)\right] \ , \ \forall s \in S$$

6 Fuzzy set of consensual solutions $\tilde{S} = \left\{\left(s_i, \mu_{\tilde{S}}(s_i)\right)\right\}$ with membership function:

$$\mu_{\tilde{S}}(s) = \min\left[\mu_{\tilde{S}_{customer}}(s), \mu_{\tilde{S}_{constraint}}(s)\right] \ , \ \forall s \in S$$

3. Case study

In the U.S., houseplant sales have increased 50 per cent in the last three years (2017-2019) to reach \$1.7 billion, according to the National Gardening Association[3]. In France, according to a study conducted by Kantar TNS[4] on 7,000 households, 75% of people bought a houseplant in 2016 which represents 21.2 million of households in the country.

Flourishing is an IoT concept composed of several smart houseplant sensors allowing people to monitor the health conditions of houseplants at any time and in any place. It is based on a dedicated cloud service, allowing houseplant sensors to connect to an outsourced server by using a Wi-Fi connection. These sensors gather condition data, such as the soil moisture, ambient temperature, humidity, and light. The visualization and the monitoring of houseplants' condition is realized through a web interface. The system is also able to inform users in real time concerning the houseplants' conditions (e.g., sun exposition, ambient temperature, etc.) or to send alert messages if the conditions required to preserve the houseplants' health need to be improved (e.g., need watering).

Fuzzy customer requirements. Flourishing is a concept intended for young customers, who are very busy and inclined to use new technologies in their daily life. Moreover, the system has to be accessible through a smartphone and must be able to adapt its recommendations according to the characteristics of different types of houseplants.

Fuzzy functions model. The Flourishing sensors have to be placed in the houseplant pots. The sensor must be able to gather condition data, such as the soil moisture, ambient humidity, temperature, and light. The data must be hosted on a server that is remotely accessible through a smartphone. The sensor must use electric energy and a Wi-Fi connection.

Fuzzy constraint model. The solution must allow an easy and ergonomic interaction with the houseplant through the web interface. The solution should also allow for easy connection to the Wi-Fi router of the customer.

[3] https://www.bloomberg.com/news/features/2019-04-11/the-one-thing-millennials-haven-t-killed-is-houseplants
[4] https://www.tns-sofres.com/publications/les-achats-de-vegetaux-d-ornement-et-pour-le-potager-bilan-2016

Fuzzy consensual model. The solution is composed of two parts: (1) a web service and (b) the connected sensors. The web service includes a website, two databases (MySQL and InfluxDB), a Raspberry Pi version 3 (server), and an Internet router with a Wi-Fi connection. The MySQL database allows for storing data, such as user accounts, houseplants and houseplants characteristics. The InfluxDB database allows for storing the data from the connected sensors. Through the web interface, the customer can monitor the health condition of the houseplants. The user can add or remove a houseplant. It is possible to manage several houseplants by monitoring in real time the condition of the houseplants (watering, light, temperature). The sensor is composed of consensus modular components: a Wi-Fi module NodeMCU ESP8266 (7.79€), an ambient temperature and humidity sensor KY015 (2.99€), an ambient light sensor DFR00026 (2.99€), a soil moisture sensor SEN13322 (3.99€), a RGB LED WS2812B (0.99€), resistors, and cables (1€) as presented in Figure 2.

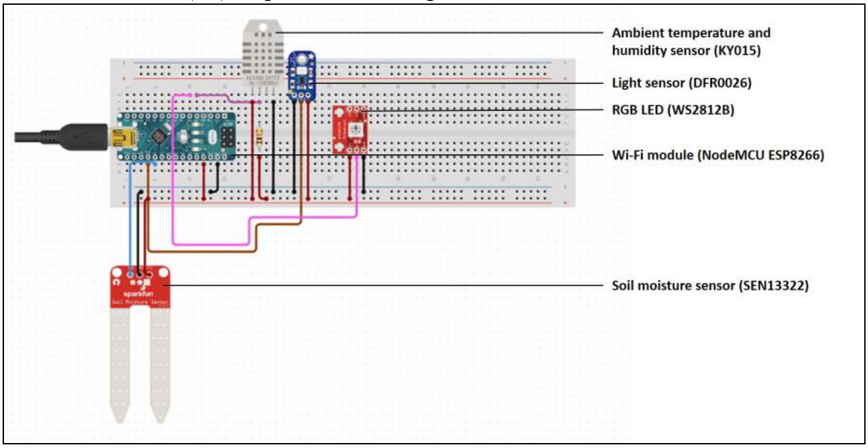

Figure 2. The architecture of Flourishing sensors.

The dashboard (Figure 3, left side) displays all the received alert messages. For example, on December 7, 2019, the houseplant asked to "increase the heating". The monitoring interface (Figure 3, right side) makes it possible to visualize data about ambient temperature, humidity, soil moisture, and light, all in real time.

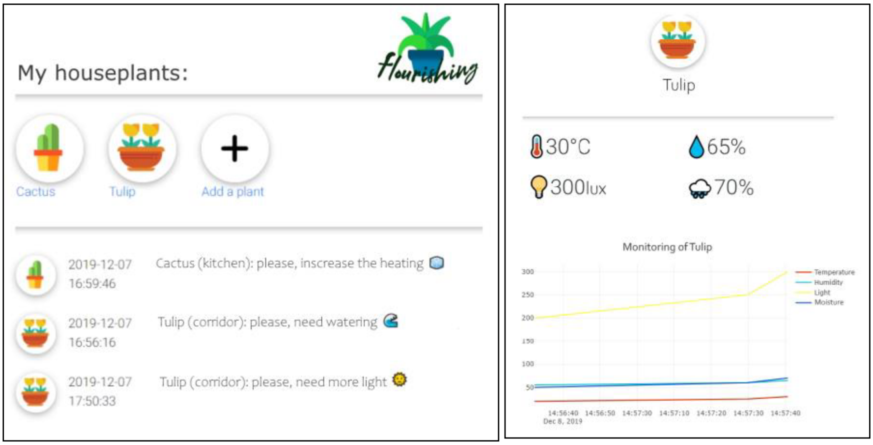

Figure 3. Dashboard with alert messages (left) - Houseplants monitoring interface (right).

4. Discussion

We assumed that consensus is the overlapping of actors' perspectives in an uncertain design situation or context. Consensus is used for working out an agreement during configuration conflict resolution.

Conflict situations in design emerge when at least two incompatible design commitments are made, coming from different actors (customer, designers) for a given subject, or when a number of actors have a negative opinion regarding the commitments asserted by the others [20][21][22][23]. Propagation of conflict, as well as backtracking without common ground for a solution, or a partial solution where the perspectives converge, can quickly lead to uncontrolled scenarios in product configuration adoptiong IoT technologies. Therefore, discerning the consensual elementary solutions creates common ground for moving toward a final global solution.

In addition, disciplines and transdisplines taking into account the subjective nature of the opinions of actors, formalized using fuzzy set theory, often reflect latent conflicts in actors' commitments. Therefore, consensus is particularly useful when uncertainty is assumed, but the rational decision-making process is required.

5. Conclusion

Modularity and design for configuration represent an efficient solution for the application of IoT technologies. The modularity offers the flexibility in design for configuration of products adopting the IoT technologies.

The fuzzy multilayer network model for configuration allows for the transition from market study into physical solutions. The approach allows for the synthesis of the best consensual solutions for the application of IoT technologies, also arguing the reason for the choice or design of a new component.

Although the fuzzy multilayer network represents the configuration in a integrated perspective, it also has some limitations, particularly its complexity for complex products. The final consensual solution is sought for a given IoT product in the situation where customers have fuzzy targets on product modules selection. To maintain coherent results, the fuzzy multilayer network should be updated dynamically.

The following questions of interest should be investigated: Is a stable solution, which results from the values of membership functions and from the computation on the fuzzy multilayer network, part of continuous change or an island sorrounded by instability? Would a small quantitative change in the membership functions of the fuzzy multilayer network, or in the degree of customer satisfaction in the requirement domain, or in the degree of expert satisfaction in the process domain, alter a solution slightly, produce very different new solutions, or perhaps leave no solutions at all? For the future, the challenge is also to develop a computer-aided integrated platform for a configurable product design integrating the IoT technologies.

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Robust CAD Modelling: Concepts and Principles for Industrial Applications

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Abstract. During product design, when many design aspects still must be understood by the design team, it is necessary to apply robust modelling approaches in order to describe the properties of the product according to the functional requirements, employing CAD system. High sensitivity to change of a CAD model can lead to unstable and unpredictable model behaviour which hinders the daily work of engineers and causes significant rework in downstream stages. Engineers need a methodology which enables them to evaluate and reduce the geometrical sensitivity of a product assembly, what the sources of variation are, their importance for the overall robustness and in what order to improve the overall design. Robustness is meant that the model structure is adjusted to react less sensitive to changes in design and model update. Robust CAD models are suitable for both downstream processes and collaboration. In this paper, we illuminate the background of CAD modelling and introduce the term robust modelling for the industrial purpose. We highlight the specific needs and expectations of the manufacturing industry. In a practical study, the application of robust modelling is shown in the design of complex machines.

Keywords. CAD, Parametric modelling, Robust modelling

Introduction

CAD systems have become indispensable tools in the product development of discrete products. As standard, modern 3D CAD systems are used as authoring tools for the design of products on a scale from screw to airplane [1]. The market is dominated by a dozen CAD systems that are usually fully integrated into holistic Product Lifecycle Management (PLM) concepts [2]. Sophisticated application methods have been developed for high-end CAD systems that need to be learned in weeks-long training courses. However, it is worth the effort because professional CAD application is an engineer's skill that has a significant impact on product development productivity [3]. This is not just about learning certain CAD functions and modules, but also about generating CAD models according to the process requirements so that they can be used without rework in the downstream processes in the entire supply chain [4]. The process compatibility of the CAD models can be assessed using various metrics [5].

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The provision of high-quality CAD data for downstream processes is the pre-requisite for the process integration in the manufacturing supply chain [6]. The fundamental vision seeks to achieve a continuous flow of information in all stages of the product lifecycle [7]. This vision affects three layers as illustrated in Figure 1. Integration is a widely requested "digital data" lever for digital transformation. It describes a product holistically with (1) domain-specific application models. It demands cohesive communication in the (2) supply chain based on CAx data streams with partners, in joint ventures and across factory plants [8]. It finally realizes (3) a fusion between up and downstream in the entire lifecycle, where digital aspects of the product solely are used as engineering, manufacturing and service bridges [6].

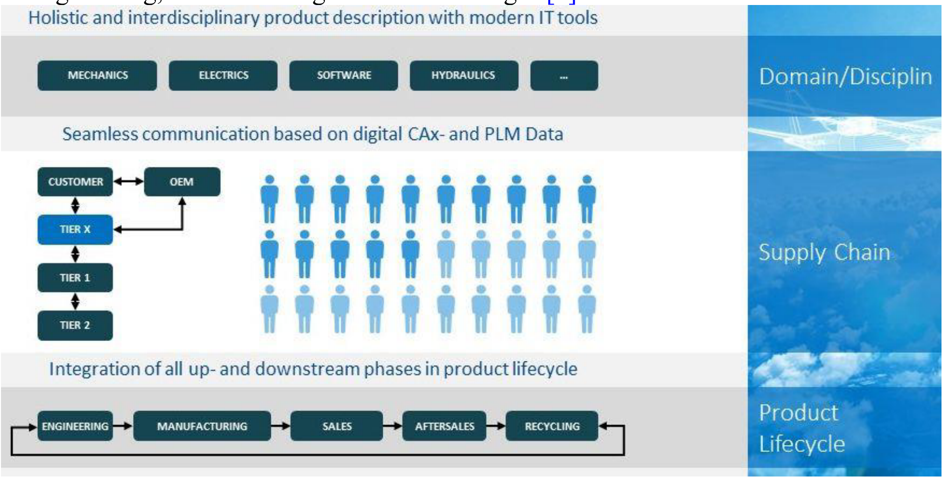


Figure 1. The integration vision in the automotive industry [6].

Thus, thanks to the consideration of inputs coming from the different disciplines, a CAD model as a multi-view object requires interdisciplinary engineering. Indeed, during the design process in the product lifecycle, a CAD model is subject of a frequent change by many stakeholders. The collaboration of various stakeholders with different points of view can lead to conflicts and misunderstandings due to, for instance, differences among domains' vocabulary [9]. Therefore, cross-modification is an important property of CAD designs. This is, in particular, the case if the CAD entities with the content of knowledge are used such as a Knowledge-based Engineering (KBE) template [10]. During the CAD design process, a tremendous issue can occur for every designer how to improve the efficiency of modification in the product design and avoid the model failure from a weak design procedure [11][12]. Several reports have been published to provide a robust design method [13][14]. It shortens the period of subsequent improvements effectively and assures product updating [15][16][17]. From this perspective, CAD modelling should reformulate its basic concepts in order to take into account the problems raised in this interdisciplinary perspective. Coping with complexity in the CAD modelling and in its conceptualization implies first to enlighten concepts and principles generally hidden in the industrial practice that can lead to a robust modelling.

The remainder of this paper is structured as follows: Section 1 provides an insight into the background of robust modelling, followed by section 2, where the conceptual principles are presented. In section 3 the method and principles of modular design are highlighted. The practical procedure is presented in section 4, followed by conclusions and outlook in section 5.

1. Background

A CAD model is a meaningful engineering representation of some product that is to be produced. A CAD model can be traced to the functional requirements and can be assessed for quality against predefined criteria. The robust product modelling consists largely of three activities: Architectural modelling, detailed component modelling and model testing [18][19]. The input into the CAD modelling is the functional model, a description of what the product is supposed to do. During CAD modelling, the functional specifications are transformed into CAD models that describe the details of the data structures, product architecture, interface, and components. The output is the CAD model which describes how the product is to achieve its functions. Essentially each CAD model produces a product.

In many development projects, CAD modelling is still an adhoc process. Normally the requirements, usually expressed in natural language, are used to make an informal design. Words have definitions but, at the same time, have no clear-cut boundaries to their meanings. In natural language, the capacity for many possible meanings is intrinsic, and the unfolding form has fuzzy boundaries and many possibilities for meaning. During CAD modelling, typically, there is little or no formal change control or design management. Thus, by the time the implementation is complete, the design has usually changed so much from the initial specifications that the original functional specification document becomes an incorrect and incomplete description of the product. Therefore, the control loop is necessary: *chaining from requirements to the CAD model*. It also means expanding this process through formalization a language of specification suitable for CAD modelling. Again the emphasis is on quality which can be checked easily [5].

The CAD modelling process is very important because it is the only phase in which the functional requirements can be accurately translated into a finished product. CAD modelling serves also as the foundation for all product engineering steps that follow regardless of which process model is being employed. Without a proper CAD modelling, we risk designing an unstable product: one that behaviour is unpredictable during changes. Or the design is a change process, one that may be difficult to test, one whose overall quality cannot be assessed until late in the production process. Each design product is reviewed for quality before moving to the next phase of product development [20]. Quality refers to both internal (e.g. modularisation) and external (visible to the other applications: e.g. Manufacturing or Finite Element Analysis.). As a consequence: a substantial rework later in the process chain could be imposed by unstable models [12].

CAD modelling assistance, as well as the translation of technical texts into the form of semi-formal or formal diagrams, can be achieved by a process of semantic analysis and representation of these texts, using previously acquired linguistic and conceptual knowledge. To analyse is to construct successive formal representations more or less dependent on a set of statements, which are, then, translated into computational treatments. Analysis modelling uses a combination of text and diagrammatic forms to depict the requirements for data, function and behaviour in a form that is relatively easy to understand, and more importantly, straightforward to review for correctness, completeness and consistency. Analysis modelling involves: a) Data modelling which defines data objects (Morphology, Material etc…) attributes (dimensions etc…) and relationships (surface, volume, speed…); b) Functional modelling, which describes how information is transformed within each module using design parameters and c) Behavioural Modelling which depicts the impact of events on the product. In essence behavioural models are used to describe the overall behaviour of the product and may use Finite Element Analysis (FEA), Failure Modes and Effects Analysis (FMEA) or Product Risk Management.

The afore-mentioned design activities essentially form four main areas of concern for designers which are: *data model*, *architectural model*, *interface model* and *component model*. In the case of an existing product, the outputs of analysis modelling are transmitted to each to each model in CAD-BOM. In the case of a new product, CAD-BOM is also created from the outputs of the analysis modelling. Thus modelling results can be classified as follows: a) *Data CAD model* which are created by channelling or transforming the function model (functional requirements) into data structures required to model the product (attributes and relationships); b) *Architectural CAD model* which defines the relationships among the structural elements of the product; it is derived from the product specifications, the analysis model (graphs, diagrams), and the interactions of the components defined in the analysis model; c) *Interface CAD model* which describes how the product elements communicate with each other, with other products, the data flow provides much of the necessary information and d) *Component CAD model* which is created by transforming the structural elements defined by the product architecture into CAD descriptions of product components.

The use of structured methods normally involves the use of graphical system models and results in a large amount of design documentation. The use of CASE tools make this process easier, results in cost reductions and because they use standard notations, it ensures that standard design documentation is produced. A structured method includes a design process model, notations to represent the design, report formats, rules, and design guidelines [21]. A given method may use one or more of the following models to represent the system: a) Data-flow model – where the system is modelled using the data transformations which take place as it is processed; b) Entity-Relationship model – describes the basic entities in the design and the relationships between them. These are popular with Database system design; c) Structural model – documents system components and their interactions; d) Object-Oriented Model – UML; e) State Transition diagrams – Models how the system reacts to (external) events.

Data-flow diagrams (DFD) are used to describe primarily data-driven systems. They are controlled by the data inputs to the system with very little external event processing. System-flow diagrams (SFD) are used to represent event-driven systems (e.g. real-time) where there is minimal data processing. In some instances, one may have to use both types of models.

2. Conceptual principles

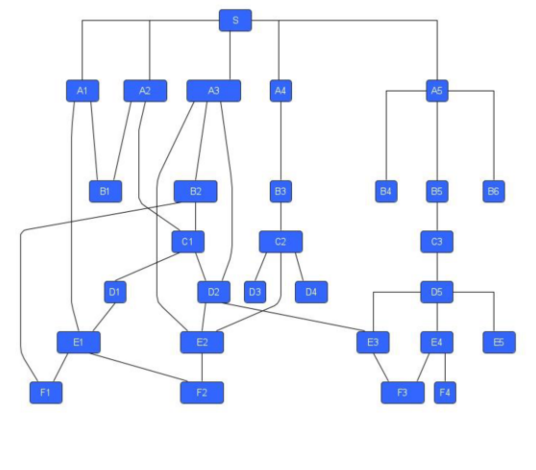
Robust CAD modelling should satisfy many criteria (Table 1). Furthermore, consistency and completeness should characterise a robust CAD modelling. Consistency across design means that all CAD models should be carried to the same depth level. Though product modelling is the result of a team of designers, it should exhibit uniformity. It means that CAD interfaces between CAD modules should be well defined and the product should look like it was designed by one individual. Also, CAD architectural structure should describe the relationship between modules and components that exhibit independent functional characteristics i.e. low coupling and high cohesion. Completeness means that a CAD model should be rational and complete, which signifies that all requirements are accounted for and all CAD models are carried to its rational completion, to the same depth level.

Table 1. Criteria for robust modelling.

Criteria and explanation
Traceability: should be traceable and connected to the analysis model.
Multi-views: should consider design multi-views (assembly, maintenance, materials…etc) that is, should not suffer from the tendency to focus exclusively on a single or limited view.
Conformity virtual-real: should maximise the conformity between the CAD model and the physical solution as it exists in the real world.
Uniformity and integration: should exhibit uniformity and integration.
Stability: should be structured to provide stable changes coming from the variation of functional requirements.
Quality:should be assessed for quality as it is being created.
Rationality: should be assessed for rationality: every CAD element should justify its existence.
Semantic content: should minimize semantic errors.

Ideally, a CAD model should be self-sustaining. CAD modularity is a way in which a product and its model can be designed such as they are self-sustaining, self-standing and suited for integration. Hence, a CAD model is divided into separately named and addressable components called modules that are integrated to satisfy design requirements. These CAD models should be capable of adapting to new design situations. CAD models are adaptive if they are composed of modules whose self-existence enhances the probability of the integration, survival and diversification. In CAD modelling, another motivation for the modularization comes from the fact that a designer cannot easily manage large CAD models comprised of a single module as the number of variables, control paths and complete complexity would make understanding virtually impossible. Consequently, a modular approach would allow for the CAD model to be intellectually manageable.

CAD model



Control Indicators

The span of control: number of levels of control within a CAD model;
Depth: the distance between the top and bottom modules in CAD model structure;
Fan-out: number of modules directly controlled by a particular module. It represents the number of inter-modular flow out of a model;
Fan-in: number of modules that depend on a particular module. It represents the number of inter-modular flow into a CAD model;
Connectivity: the set of CAD components that are related directly by a given CAD component;
Indirect Connectivity: the set of CAD model components that may be related by a given CAD component.

Figure 2. Tree diagram of CAD model and Indicators.

However, one cannot subdivide CAD product indefinitely to make the effort required to understand or develop it negligible [22]. This is because as the number of increases (causing the effort to develop them to decrease), the effort (cost) of the associated integration process increases. The main principles for CAD modularity are: a) Modular decomposability - provides systematic means for breaking product into modules; b) Modular composability - supports adaptability, reuse and integration of existing modules in new systems; c) Modular understandability - module can be understood as a stand-alone unit; d) Modular continuity - side-effects due to module changes minimised; e) Modular protection - side-effects due to processing errors minimised.

CAD modelling deals with changes – changes in product morphology, changes in product behaviour. Smooth and continuous changes should be planned. Abrupt changes, followed often by the destruction and the redefinition of the whole model, should be avoided. Therefore, CAD modelling should clearly define the scope of the effect of all modules. The scope of the effect of a module is defined as all the other modules that are affected by a decision made by that module. During the progress of the CAD model, several control indicators need to be continuously monitored (Figure 2).

3. CAD Modular Design and Complexity

The aim of CAD modular design is high cohesion and low coupling which ensure the functional independence of modules. The cohesion of a CAD model of a module measures the degree of relatedness of functions within the module. It gives the qualitative indication of the degree to which a module focuses on just one function or task. A cohesive module performs ideally a function. Coupling expresses the qualitative indication of the degree to which a module is connected to other modules. Coupling measures also the relative interdependence among functions. A CAD modelling method is proposed for successful modular design (Figure 3). It comprises the principle of decomposition-composition (modules may be exploded e.g. one becomes two modules or imploded to reduce coupling and improve cohesion) and the principle of factoring: determining what properties belong to a given module and closely related properties should be grouped together .

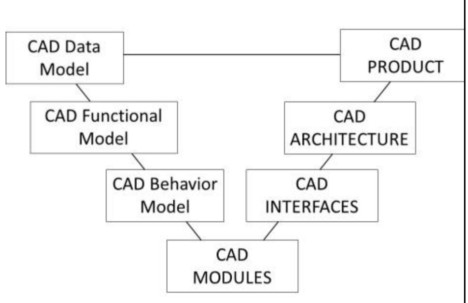
Proposed CAD modular design method	**Rules for modular design**
	(a) define modules whose function is controlled from functional requirements; b) ensure controlled entry modules from functional requirements, avoid uncontrolled connection e.g. uncontrolled relationships into another CAD module; c) keep the scope of effect of a module within the scope of control for that module defined from functional requirements; d) design and evaluate module interfaces to reduce complexity and improve consistency; e) optimize the number of fan-out and fan-in.

Figure 3. Proposed CAD Modualr Design.

Models should be continuously tested and evalauted during CAD modelling to ensure that the functional specifications have been accurately and completely incorporated into the design [5]. The quality of the CAD model depends strongly on its complexity. Coupling and cohesion are two functional characteristics which impact the complexity of a CAD model. Functional coupling and functional cohesion are two metrics to measure the complexity of a CAD model (e.g. module or component) defined as:

Functional coupling = (number of inter-signature)/(total number of data signature)
Functional cohesion = (number of data signature)/(total number of data signature)

where: a *data signature* is any occurrence of elements (geometry and constraints) in a model; a *feature* within a model is the collection of all the elements that can affect the values of some function of interest; a *data feature* is the collection of all the data signature in the feature that will affect a specific function of interest; an *inter-signature* are the data signature in the model that lies in more than one data feature.
Other metrics vocabulary complexity, which measures the volume and the effort of the CAD model implementation can be introduced to measure the complexity of the CAD model. To measure the control flow and the inter-modular flow in a CAD model, the cyclomatic complexity and information flow complexity can be used. Cyclomatic complexity depends on the number of CAD elements and its topology.

4. Practical procedure

The robustness of a CAD model needs to be incorporated from the first sketch on, avoiding an unstable model basis. Otherwise, the time saved upfront by fast, "free" modelling by generating a flow of features in an intuitive, creative, but arbitrary order is eventually spent later by either a lower ability for collaborators to interrogate and rework models due to unclear design intent, or a lower changeability of the model by many failures which occur during an update on changes because such a model is not stable enough. A practical example is the design of complex industrial equipment such as production lines [23]. The implementation of a new production line for innovative composite boards starts with the analysis of customer-specific data and customer production requirements which lead to a 2D layout (Figure 4). With these defined processes and created functional sketches, the individual machines are implemented by 3D CAD modelling. The production possibilities of individual manufacturing companies are taken into account, such as, for example, the bending machine and tools, cutting equipment and in the CAD software some settings are already taken into account (Figure 5). The 3D data obtained from individual machine components are read directly in the production machine without further processing and automatically translated into machine language. This saves programming time and machine changeover time, and the components can be quickly and productively produced.
Basically, there are few approaches to implement or facilitate robust modelling: modular structure (1), use of component interfaces (2) and intelligent naming (3).

4.1. Modular structure

Modular structure (1) can be achieved in different ways [24]. A CAD system-independent method basically combines multiple, simple (10 – 15 entities) sketches with just a few references as a basis for features in a model tree which propagate the parameters and describe the progression of the design. In such a way, the sketches control the features. Otherwise, sketches become unruly and hard to modify. Keeping sketches lean helps avoid model failures in case of change and update. At general, chamfer or blend features should be added afterwards, outside the sketch to don't impact the model basis. This detail geometry should not impact the structure of the model and can be easily suppressed or excluded when the model needs to be simplified. Alternatively, a model can be created with the fewest number of features possible which provides a flat, robust structure with a low number of interdependencies. The drawback of this approach is that each of these features tends to get more and more complex. The robustness issue is moved to such features which are difficult to modify due to the unpredictable model behaviour. Their design intent is not obvious. If features are subdivided based on their function, the model tree becomes more clear.

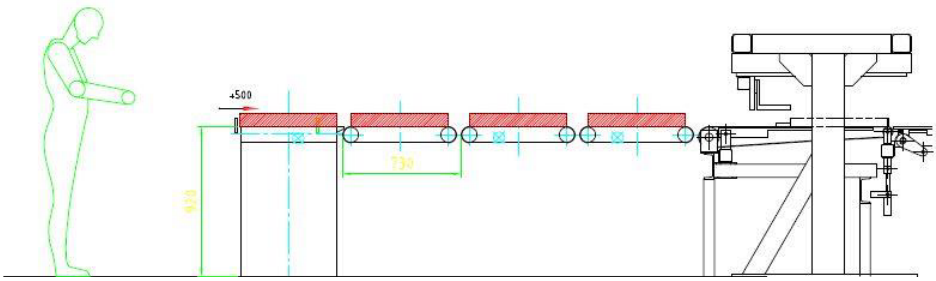


Figure 4. Sketch of the modular structure.

4.2. Use of component interfaces

Use of component interfaces (2) describes an approach to assemble predefined library components which can be singular features or patterns of features (transversal, circular etc). This can drastically reduce the number of references and constraint, and, therefore, increase the stability of the model. Such an approach impose a significant pre-work in the creation of a library and its elements. At general, interfaces require adaption of each library component. On the other side, less experienced users get a good hint to deal successfully with such designs. It can be combined with the publish function which exists in all leading CAD systems and provides just an explicit part of a CAD model or a feature to be used as a reference od constraint. This is particularly beneficial either to share the same geometry in multiple downstream components or to distribute such geometry with an owner of the source geometry among team members in a concurrent engineering team. The published geometry is set to read-only and an invariant which improves the model robustness.

4.3. Intelligent naming

With intelligent naming (3) an advanced technique is meant to give appropriate names to the generic names. It can be used additionally to support both previous approaches in order to achieve better transparency of complex CAD models. If the user omits to define his own nomenclature, the model tree becomes a mess of generic features which are hard to distinguish and, therefore, hard to edit because no one can recall singular one. Such a circular renaming can be supported by macros. Additional way to mark features is to use annotations which are available in all CAD systems. This can help to later identify the function of a feature or group of features. Use of groups and layers can also improve the readability of a CAD model. Depending on the CAD systems, groups can be built according to several criteria (function, reference, entity). Grouped features must be sequential in the tree.

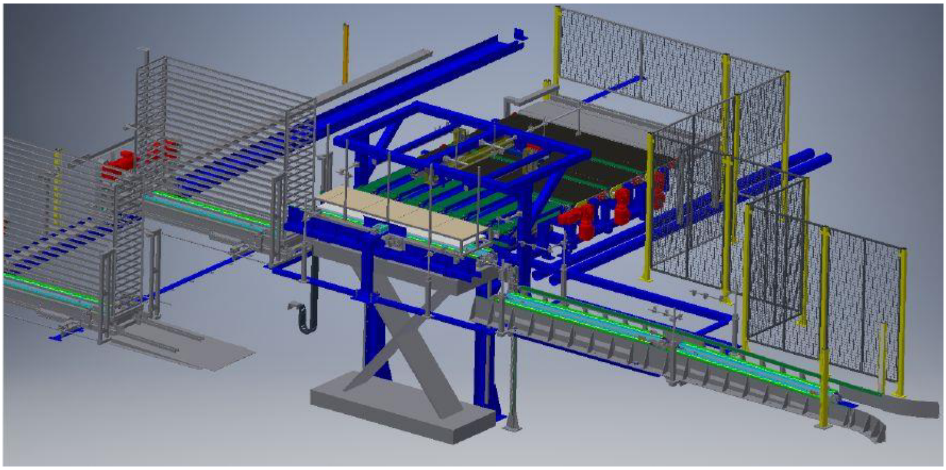


Figure 5. CAD model of the complete machine.

5. Conclusions and outlook

The article presented here has illustrated how robust modelling is a substantial method of CAD design and can be achieved efficiently by applying appropriate techniques. It was explained how the required input parameters impact the design process. Conceptual principles of modelling were analyzed too. Afterwards, the whole process with quality metrics was explained in detail. Impact factors for effective modular design were described. Such improved process reduces the effort to generate CAD models so that the utilization can be beneficial for downstream processes in the supply chain [23]. It is important to say that such generic approaches basically don't require specific CAD licenses and, therefore, can be included in the basis of CAD training. Most recommendations are CAD system independent.

Practical application was demonstrated based on complex industrial equipment (product line for composite boards). Based on robust modelling, various methods of detail design can be implemented e.g. high-fidelity definitions of aircraft external shapes [26]. This approach also emphasizes the role of the object-oriented approach and of well-established software design patterns in the development of a modular software library independent of low-level geometric modelling kernels. This can enhance modularity further.

Robust modelling is a good basis for further process improvements. The use of intelligent templates, on the one hand, achieved a high degree of automation and on the other hand, created the possibility of expanding the CAD environment for specific downstream processes [10] (e.g. automated provision of visualization data [4]). As a long-term solution, the use of comprehensive skeletons can be beneficial for a family of design problems. Based on robust modelling, such an approach can be also adapted to various expert areas and implemented as specific workbenches.

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In the Era of Digitalising Shop Floor Management: In Blissful Ignorance of Superfluous Work

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Abstract. This study aims to understand the extent of superfluous work at shop floors and suggests some managerial opportunities for reducing superfluous work. Drawing on the abductive reasoning, the research systematically combines a theoretical conceptualisation of decision-making processes in a digitalised manufacturing with an empirical enquiry of a smart manufacturing. The paper reveals superfluous work if decision-making processes cross disciplinary and/or organisational boundaries. Superfluous work occurs because of lacking data and information to guide reflective thinking and knowledge sharing. In relation to high complex decision making the ongoing implementation of workarounds does also cause superfluous work. Prerequisites for reducing superfluous work are accessibility of applicable data to guide reflective thinking and knowledge sharing.

Keywords. Shop Floor Management, decision-making, smart manufacturing, superfluous work, knowledge sharing

Introduction

Companies witness an ongoing transition towards smart manufacturing [1], which makes Shop Floor Management (SFM) decision-making topical. SFM decision making is pivotal for an efficient execution of manufacturing [2], but to what extent if any does decision making in a smart manufacturing influence the amount of superfluous work?

Superfluous is defined in Cambridge English Dictionary as "*more than is needed; extra and not necessary*". Superfluous work is often considered as value adding by practitioners carrying out the work, but basically it does not add value [3]. Superfluous work is hidden waste [4]. Superfluous work occurs because of practitioners lack data and/or information to accomplish the decision-making process. In this research superfluous work equals the gap between necessary work and actual work spent on accomplishing decision-making. Necessary work is the minimum work if having access to reliable data and can apply this; actual work = necessary work + superfluous work.

In a smart manufacturing set-up the complexity of decision-making varies [5]. Straightforward decision making is handled within disciplinary boundaries, but complex issues call for collaboration across disciplinary and/or organisational boundaries [6]. Wognum et al. [7] agree and argue that the development and implementation of smart manufacturing calls for transcending disciplinary boundaries, mainly due to both social and technical issues are ill-defined and thus characterised by high complexity.

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In the current era of digitalising manufacturing equipment and information systems, SFM decision making draws still on principles developed in mid-50s [8] and applied information systems appear as they did 20-30 years ago [9]. Given that digitalised equipment enabling data-driven decision-making has not yet entered shop floors, SFM is most likely characterised by superfluous work. It seems managers in companies live in blissful ignorance of these consequences.

To gain an understanding of SFM decision making in smart manufacturing set-ups this study aims to understand the extent of superfluous decision-making work and suggests some managerial opportunities for reducing the amount of superfluous work. The following two research questions guide the study "*to what extent does decision-making complexity influence the amount of superfluous work*?" and "*what are the prerequisites for reducing superfluous work*?". To answer these two research question the study draws upon three cases from a company operating globally. The three cases explicate the characteristics of SFM decision making; one case addresses decision making within disciplinary boundaries, and two cases elaborate decision making across disciplinary/-organisational boundaries. By juxtaposing the empirical findings from the three cases with related theories, we conceptualise a framework with the purpose of clarifying the consequences of and suggestions for reducing superfluous work.

The contributions are as follows: Low decision making complexity does not lead to superfluous work. Medium decision-making complexity is protracted and superfluous work occurs in relation to gain access to applicable data and information. Handling highly complex issues are a lengthy process back and forth disciplinary/organisational boundaries, yet the extent of superfluous work is mainly related to implementing work-arounds. Prerequisites for reducing superfluous work are accessibility of applicable data to guide reflective thinking and knowledge sharing.

1. Theory

A digitalised shop floor is an arrangement of digitalised manufacturing equipment and information systems to manage employees and optimise the flows of materials and information. Some researchers conceptualise a digitalised shop floor as a Cyber Physical Systems [10; 11] and as data analytics practices [12], which enables information transparency [13] and high utilisation of resources [2; 14].

The industrial rethinking represented by Industry 4.0 increases the complexity of decision-making processes, the diversity of data and the pace of changes to be handled [15; 16]. Despite the increasing complexities it is expected that machine learning algorithms [17], interoperability [10; 18] and artificial intelligence [19] lead to a situation where decision-making processes are accomplished by digital technologies. Implicitly, this stream of research gives technologies deterministic effects, meaning that decision making will be automatised and thus handled without the involvement of practitioners. However, it is implausible that machine learning, algorithms and artificial intelligence will exceed practitioners' creative intelligence, social intelligence, intuition and judgement in terms of decision making. Thus, in the future decision making involves both digital technologies and practitioners' knowledge [8]. SFM decision making is a process of applying accessible data and information with the purpose of eliminating waste.

Superfluous work is a kind of hidden waste. Lean and elimination of waste go hand in hand [20]. Waste is often categorised into different types of waste, which are unnecessary transportation, defects, overproduction, waiting, excess inventory, unnecessary movement, incorrect processing and underutilisation of people and their creative input for improvements [21]. Sutrisno et al. [22] suggest four digital waste types, which are i) obsolete data and information, ii) low accessibility of information, iii) scattered information thus lack of shared understanding, and finally iiii) inappropriate coordination.

While the waste factors suggested by Womack and Jones [21] are directly perceptible for the involved practitioners, the four types of factors proposed by Sutrisno et al. [22] are hidden waste. Decision making based on these hidden waste factors - obsolete information, low accessibility of information, scattered information across disciplinary boundaries and thus lack of shared understanding and finally inappropriate coordination across disciplinary boundaries will often result in slow running or idling equipment, waiting time, rush orders, overtime, expensive transportations, unnecessary movement of materials and rescheduling [21]. In addition, the hidden waste factors lead to superfluous work [2; 4], which means that practitioners carry out work they consider as being valuable, but basically it does not add any real value for the company. The hidden waste factors and thus the seed for superfluous work originate from low accessibility and applicability of data and information.

"*Without data, you're just another person with an opinion*" (W. Edwards Deming). This old saying highlights the importance of having access to data, which however is insufficient to carry out SFM decision making at digitalised shop floors. Rather, SFM decision making is enabled by the applicability of accessible data and information. In other words, data-driven decision making, accessibility and applicability are inseparable.

A smart manufacturing set-up causes increasing diversity of data [12]. The diversity of data are categorised as structured-, semi-structured- and unstructured data [13]. This combined with a general lack of syntactic-, semantic- and cross-domain interoperability [18] forms isolated information islands [23] and thus low accessibility of data and information. Information islands obstruct practitioners in gaining access to and in applying data to accomplish data-driven decision-making. The low information transparency causes to isolated decision-making.

Required data for enhancing decision-making responsiveness depends on the complexity of the problem and whether or not, the involved practitioners are capable of applying the accessible data to identify and implement a solution. Data-driven decision making is a process of converting data and information into embodied knowledge and knowledge sharing within and across disciplinary boundaries [6]. Given that the applicability of data and data-driven decision-making are inseparable, the value of "big data" depends solely on the information and knowledge, which can be derived from the data [24].

SFM decision-making and knowledge sharing unfold in symbiosis, which require practitioners to carry out reflective thinking [25]. Reflective thinking is an inquiry process [26] in which each of the involved practitioners' decision-making actions are "guided" by observations of cues from the surroundings and his/her experience [27]. These cues are malfunctions at the shop floor level, other practitioners' actions as well as accessible data and information. Experience is embodied and situational and according to Dewey [28] to activate reflective thinking, the cues from the surroundings must cause disturbance in the habitual way of decision making. This highlights the importance of the old saying "well begun is half done" and thus conceptualises decision making as a progressive inquiry process of the conditions at the shop floor. SFM decision making involves ongoing interplay between each practitioner's experience and observations; as for the latter, interpretation of social and technical conditions within the particular shop floor. Thus, the accessibility and applicability of data and information should be tailored to the complexity of the decision-making processes.

SFM decision making involves both technical and social matters [8; 29; 30]. The definition of decision-making complexity is not unequivocal. Anderson and Törnberg [29] distinguish between complex and complicated issues. Complex issues deal with social matters as interactions in social network, which involves high redundancy, unpredictability and amplification of disturbances. The focal point for complicated issues is technical matters. It focuses on issues related to technologies consisting of scale-separated level of hierarchies, predictability and decomposability. By combining complex and complicated issues three groups of decision-making processes are identifies; simple, sub-wicked and wicked decision making.

Researchers argue [7; 12; 29] that wicked problems are ill-defined problems, which solution requires transcending professional disciplines. Drawing on this understanding and the work of Liker and Meyer [20] and Hertle et al. [5], Mathiasen and Clausen [6] suggest that; i) low complexity decision-making is handled within disciplinary boundaries of shop floors; ii) medium complexity issues necessitates interdisciplinary decision-making cutting across disciplinary boundaries; iii) high complexity decision-making requires transcending disciplinary boundaries.

2. Methodological considerations

This explorative study aims to understand the extent of superfluous decision-making work and suggests some managerial opportunities for reducing the amount of superfluous work. Accordingly, the paper follows Yin's [31] advices to use a case research method; a single case with three embedded cases are selected. The logic of inquiry is abductive and draws on Dubois and Gadde's [32] systematic combining, who suggest concurrent elaboration of the theoretical conceptualisation, the processing of data, the drawing up the cases and the analyses.

In an explorative study the learning opportunities from the empirical material is pivotal [33]. The selected case company has recently gone through a transformation towards a smart manufacturing set-up. The criterion for selecting the three embedded cases deals with opportunity to learn [33]. Diversity in terms of complexity of decision making is the criterion for selecting the three cases.

The data collection consists of observations, interviews and second-hand information. Regarding the observations, one of the authors has regularly visit the case company before, during and after the transition to the smart manufacturing set-up. Being present at the shop floors and taking the role of "complete observer" (see [34]) gives an understanding of decision-making processes, abbreviations and expressions applied by the practitioners. Likewise, it paves the way for several unstructured interviews. In addition to many unstructured interviews, two semi-structured interviews are conducted with the plant manager. Due to confidential reasons, the semi-structured are not taped. Instead, notes are taken and just after each interview notes are typed up and reflections from the interviews are added to the document. Final, both authors have many years of experience from working in manufacturing companies.

By systematically combining our theoretical and empirical understanding, the collected data are coded; i.e., decision-making complexity, accessibility and applicability of data and information and the consequences at the shop floor. Based on this coding, each of the three cases is analysed separately to expose the extent of superfluous decision-making work including waste. A cross-case analysis juxtapose the findings with the purpose of revealing managerial opportunities for eliminating superfluous work.

3. Cases

The case factory, pseudo-named "Factory", is part of a global conglomerate. Factory is located in a high-wage areas and consequently capacity utilization and efficiency are fore fronted. Factory has been operating within the Fast-Moving Consumer Goods industry for several decades and has a good reputation in terms of delivering on time.

Factory has designed and constructed a completely new factory and subsequently all assembly lines have been renewed and highly automated. Currently, Factory has the highest degree of automation and digitalisation of manufacturing equipment in the conglomerate. The assembly lines are fully automated and various sensors along the lines collect performance data automatically, which ensures a reliable and appropriate data foundation. Accordingly, Factory has implemented an on-line system for monitoring and following up on Overall Equipment Efficiency (OEE).

Material handling at the end of the assembly lines is fully automated. After each of the assembly lines a conveyor belt transports the finish goods to the material handling department, where robots handle the palletising and data registration. The data registration requires retrieving and storing production and customer related data in the ERP systems, printing and fitting on barcodes, and inventory registration. The data registration involves several IT-systems, which means the interfaces among the IT-systems are very complex. The development and implementation of the material handling systems have required across discipline and organisational boundary collaboration.

In line with the other factories in the global conglomerate, Factory follows the lean principles for performance management and continues improvement. The OEE system is a useful monitoring tool and Factory reports weekly OEE performance to top management. However, the OEE application is a stand-alone system, which is neither integrated with the Enterprise Resource Planning (ERP) systems nor other IT systems being applied in the conglomerate. This lack of interfaces imposes complexity in term of using the accessible information to visualise and analyse different types of data; for instance OEE performance, delivery performance, maintenance and quality. According to the plant manager, approximate 60 % of the collected data are used. In this regard two problems are put forward; i) practitioners do not have sufficient knowledge to interpret and thus use the data to identify the root-cause of the problem; ii) despite data are collected automatically by sensors, practitioners operating the assembly lines have to manually enter error codes, which has a negative impact on the reliability of the data stored in the IT-systems.

To facilitate knowledge sharing within each department and at the plant level three different board (kaizen) meetings are conducted; i) assembly line board meeting in which blue-collar workers, technicians and departmental manager participate; ii) departmental board meeting across the assembly lines having the purpose of coordination and identifying problematic issues, where the participants are the departmental manager and few appointed blue-collar workers and technicians; iii) plant board meeting discussing main issues across departments and assembly lines, participants are plant manager, departmental managers and lean manager. In general, decision making within departmental boundaries are handle promptly, but knowledge sharing involving practitioners from other department, factories or external business partners are a protracted process. In the following the three decision-making cases are briefly presented in table 1; these make up the empirical foundation for the following analytical chapter.

Table 1. Three decision-making cases.

Problematic issue	Knowledge sharing	Consequences	Duration
Low complexity decision making			
Weight issues on product produces	Ongoing weight measuring characterised by high visibility are directly understandable	High scrap, reduced OEE	½ hours
Infeed of material to assembly line not running	High accessibility of structured data, which are useable for practitioners enables knowledge sharing within shop floor	Downtime – idling and/or slow running equipment. Reduced OEE	Three hours
Incorrect filling of products	Only downtime data is displayed/available, but the technicians have experience with handling the problem	Downtime – idling and/or slow running equipment, reduced OEE	Five hours
Medium complexity decision making			
Software error OEM equipment	Only downtime data is displayed/available. Software related data are only available for supplier. Supplier can access and use data	Downtime – idling and/ or slow running equipment. Reduced OEE	Two months
Serial defect in inbound materials	Factory lacks data – only approved product specification data are available. Serial defect data are forwarded to purchasing/suppliers	Downtime and scrap of material. Postponement of deliveries. Reduced OEE	Several months
Software interfaces	Only OEE data available for Factory, limit data of Software. Solutions implemented by external partner	Slow running equipment. Reduced OEE	Four months
High complexity decision making			
Low robustness of technical solutions	No data accessible and neither suppliers nor Factory knows the solution	Recurrent slow running equipment. Reduced OEE	One year
Low dependability of suppliers	Delivery performance data are available, but these data are not useful to enhance dependability	Recurrent stock-out of inbound material – planned downtime	Several years

4. Analysis

This research sets out to explore the extent to which decision-making complexity influence the amount of superfluous work?" and "the prerequisites for reducing superfluous work?".

As illustrated in the three cases, low complexity decision making occurs either directly at the assembly line or at one of the three board meetings. Low complexity decision making represents the majority of problematic issues being handled at shop floor level. The consequences are minor due to the fact that the duration from detecting to handling the abnormal situation is short. At the shop floor scrap of material, idling and slow running equipment are the cues for the occurrence of an abnormal situation. Too high scrape of material and reduced OEE are the cues at the board meetings. This kind of cues are sufficient to trigger the practitioners' reflective thinking and knowledge sharing. In general the required data and information are accessible from various stand-alone IT-systems. In particular, structured OEE data combined with the Lean A3 way of structuring the decision-making processes is applied to ensure that problems are handled promptly without any delays. In other words, the amount of superfluous work is minimal.

The consequences of medium complexity issues are perceptible at the shop floor. Cues highlighting the problematic situations are similar to low complexity decision making; at shop floor these are scrap of material, idling and/or slow running equipment, and at board meetings the cues are in general too high scrap and reduced OEE. Despite the daily consequences are equal to low complexity issues, the duration of operating with increased scrape and low OEE is rather long-term – from two to four months. The decision-making process is protracted. Cues from the physical shop floor - high scrap, idling or slow running equipment - or OEE/scrap data and information visualised at one of the three board meetings trigger the decision-making process. Either lack of experience with the particular problematic situation or low accessibility of structured, semi-structured and unstructured data/information to guide reflective thinking results in this kind of decision-making processes is unconsciously put on standby for a while. In the endeavour to continue or restart the decision-making process, technicians and/or the lean manager draws on the Lean A3 way of conducting root-cause analyses. Normally, it is necessary to cross disciplinary and/or organisational boundaries for gaining access to useful information and knowledge. This across disciplinary/organisation boundary collaboration is resource demanding and time-consuming. It other words, data and information are transferred back and forth disciplinary/organisational boundaries, which results in superfluous work for both Factory and external actors.

As for high complexity issues the consequences are partly perceptible at the shop floor in form of recurrent idling, slow running equipment and rescheduling of job orders. Workarounds implemented by technicians in collaboration with external actors mitigate the majority of the perceivable consequences at shop floors, but these are resource demanding. Likewise, the consequences of recurrent stock-out are not directly visible at the shop floor, but the ongoing rescheduling of purchase and job orders causes a lot of superfluous work for the administrative departments and managers at the shop floor. In general, the start-up of these decision-making processes has much in common with handling medium complexity issues. However, timewise the process is very protracted, from one to several years in which data, information and proposed technical solutions are handed back and forth disciplinary and organisational boundaries. These time-consuming processes might be due to the facts that; i) Neither Factory nor the involved external actors have sufficient accessibility of data and information to guide reflective thinking and thus knowledge sharing towards implementing a proper solution, which results in the across boundary interactions are characterised by a trial and error approach. ii) The outcome of the decision making requires changes in organisational procedures including SFM procedures and in the technical equipment, which requires technicians to gain new experience.

5. Discussion and conclusion

The analysis of Factory demonstrates three kinds of decision-making processes in a smart manufacturing set-up. In general, because of a high degree of automation throughout the plant Factory has a high effective manufacturing.

This effectiveness characterises low complexity decision making, which normally are handled directly at the shop floor. Required data and information are directly accessible in the stand-alone OEE application or retrievable from log files embedded in the equipment, which are sufficient to guide practitioners reflective thinking. This promptly decision making means that; i) the hidden waste factors in form of obsolescent-, low accessibility-, scattered data/information and inappropriate coordination (see [22]) do not influence this kind of decision-making processes; ii) the consequences of the directly perceivable waste as scrap, idling and slow running equipment are reduced (see [21]); iii) the gap between actual time spend on handling the malfunction and necessary time is minimal, which means the amount of superfluous work is minimal.

Complex decision-making requires collaboration across professional and/or organisational boundaries. Hidden waste factors influence both medium and high decision-making complexity, but in different way. As for medium complexity issues, to guide reflective thinking various data and information are transferred back and forth disciplinary/organisational boundaries. The analysis indicates that it is resource-demanding to gain access to applicable data and information, and that the managerial focus is on handling the malfunction and thus accepting perceivable waste at the shop floor. Medium decision-making complexity is protracted and a gap between actual work and necessary work for handling the malfunction is apparent, which means the decision-making processes are characterised by superfluous work.

Handling highly complex issues are a lengthy process in which data and information are transferred back and forth disciplinary and organisational boundaries. Accessibility of data and information is a challenge, but the applicability of the scattered data/information seems even more challenging. In this regard, obsolescent-, low accessibility-, scattered data/information and inappropriate coordination lead to superfluous work. Because of the lengthy decision-making process, technicians in collaboration with external actors implement workarounds in the attempt to mitigate perceivable waste at the shop floors, but these workarounds are basically superfluous work. Thus, highly complexity decision making are characterised by two kind of superfluous work, transferring data and information back and forth boundaries and implementing workarounds.

The necessary work for accomplishing a decision-making process depends on the expe-rienced complexity. The necessary work is the minimum work if all involved practitio-ners have access to reliable data and can apply these to guide reflective thinking and knowledge sharing; often necessary work differs from the actual work invested in hand-ling the problematic situation. To gain an understanding of the difference between necessary and actual work this study suggest drawing on the principles of the lever-arm.

As illustrated in figure 1, the grey box on the left side of the lever-arm symbolises the actual work for handling a problematic issues. A part of the actual work consists of superfluous work, depicted above the dotted line. The grey box on the right side of the lever-arm illustrates the necessary work. As it appears from the figure, superfluous work causes disequilibrium between actual and necessary work. The requisite for gaining equilibrium is to move the fulcrum towards the actual work box. If the fulcrum falls directly in between the actual and necessary work boxes the decision-making processes are very effective; i.e., no superfluous work is done.

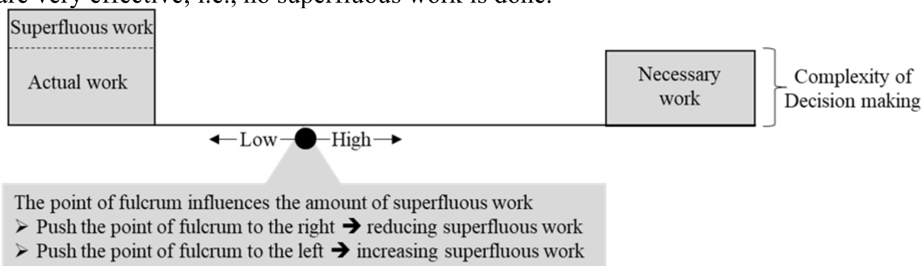

Figure 1. Superfluous work causes disequilibrium.

The placement of the fulcrum depicted at the lower part of figure 1 depends on the accessibility and applicability of data and information to guide reflective thinking and knowledge sharing when accomplishing a decision-making process. Low accessibility and applicability push the point of fulcrum to the left and thus increasing the amount of superfluous work, while high accessibility and applicability push the point of fulcrum to the right and thereby reducing superfluous work.

As elaborated in the above, accessibility and applicability of data and information are the prerequisites for reducing superfluous work. Accessibility of data requires the formation of a reliable data architecture in terms of collecting, coding and storage data (see [13; 24]) and the establishment of sufficient interoperability among IT-systems to retrieve data (see [10; 18; 23]). However, the value of the accessible data depends solely on the information and knowledge sharing, which can be derived from the data. Reflective thinking is individualised (see [26]), but the practitioners' knowledge sharing does also involve social interactions. Knowledge sharing unfolds as a process of social interactions either within or across disciplinary/organisational boundaries in which the involved practitioners have "reflective conversation with" the accessible data (see [6]). In other words, accessibility and applicability are two side of the same coin; to reduce superfluous work managers should take into consideration both side of this coin.

Smart manufacturing is portrayed as an appropriate way to follow as it ensures an effective execution of the manufacturing processes and enables promptly date-driven decision making. This study demonstrates that the transition to the smart manufacturing set-up has enhanced the effectiveness of the manufacturing. However, the company being studied has not fused the flows of data/information, materials and digitalised equipment into CPS systems as suggested by Tao and Zhang [10], Qi et al. [11], eliminated information walls proposed by Dai et al. [13] and thereby enabled promptly data-driven decision making [2]. Actually, shop floor board meetings draw on analogue information written or printed on papers or whiteboards. Likewise, decision making crossing disciplinary/organisational boundaries are characterised by a lot of redundant work because of low accessibility of applicable data and information. These findings echo the viewpoint that practitioners involved in SFM decision making have not yet enjoyed the benefits of the current digitalisation of manufacturing [35]. Besides that practitioners do also face increasing decision-making complexity (like [16]) and managerial awareness for enhancing responsiveness (like [15]). Findings in this study indicate that the way to go for harvesting all benefits of smart manufacturing in terms of data-driven decision-making is still long and resource demanding. Apparently, companies involved in the transition towards a smart manufacturing set-up are successfully implementing an effective execution of manufacturing, but in blissful ignorance of the benefits of data-driven decision making. As this paper illustrates, the consequences are a lot of superfluous works at shop floors, across disciplinary and organisational boundaries.

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Components of the Preliminary Conceptual Model for Process Capability in LGPD (Brazilian Data Protection Regulation) Context

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Abstract. A capability model describes the complete set of features that an organization requires to execute its business model or fulfill its mission; the user's environment must be increasingly included in the design and development of necessary and desired solutions. For this, the development of the model and its application are central issues. An account should be taken of legislation involving the protection of individuals' personal data in any relationship involving the processing of information classified as personal data; as well as its impact on public and private companies across the country, considering any size and market segment, and taking into account the need to comply with legal requirements efficiently and sustainably, mitigating risk factors. Transdisciplinarity characterizes this research, as the digital transformation process integrates legal, technological aspects, risks, business analysis, good practices and standards of information technology management and digital compliance. This paper addresses this problem by analyzing the main areas of contribution to the assessment of process capability for digital transformation concerning cybersecurity in the context of personal data protection legislation. Finally, the main components of the future capability model are presented.

Keywords. Process Capability, LGPD, transdisciplinary engineering.

Introduction

A capacity model describes the complete set of resources an organization requires to execute its business model or fulfill its mission. For this, the development of the model and its application are central issues. This means that data needs to be actively managed at all stages of the data life cycle (that is, collected, stored, analyzed, shared, and archived) through defined data practices, standards and policies. Law 13.709 / 2018 impacts private and public companies across the country, considering any size and market segment, taking into account the need to meet requirements efficiently and

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sustainably. Legislation (LGPD – Lei Geral de Proteção de Dados - General Data Protection Law) involving the protection of individuals' personal data in any relationship that involves the processing of information classified as personal data. The business process must take into account the need to meet legal requirements efficiently and sustainably, mitigating risk factors.

This work is part of the doctoral thesis of one of the authors and is a direct result of the systematic literature review. It is an initial study that forms the basis of the doctoral thesis, therefore, with still partial results. Information security is not only a matter of Information and Communication Technology organizations, but also of increasingly interconnected industrial and service environments; they are no longer isolated corporate systems and must be protected. Systems of service companies are especially vulnerable to attacks and threats such as people's mistakes, incidents on employees' devices, cyberattacks, disgruntled workers, external access, cloud computing, and data leaks. Transdisciplinarity characterizes this research, as the digital transformation process integrates legal, technological aspects, risks, business analysis, good practices and standards of information technology management and digital compliance.

The legislation is new, and the work intends to help society and companies to think about the adequacy strategy since there is no single product or action that guarantees the suitability of a company to the LGPD. It is understood that there must be a clear strategy, which includes legal, technological, and management process aspects.

This article addresses this problem by analyzing the main areas of contribution to assessing the capacity of the digital transformation process concerning cybersecurity in the context of personal data protection legislation. The main objective is to present the main components of the future capability model to understand the functionality and the underlying flows in the LGPD context.

1. Research Design

An initial (preliminary) analysis of the literature related to the processing capacity and the process improvement models published in the leading magazines from 2000 to 2019 is made. The initial step is to define the set of guidelines that served as a starting point for this work, based mainly on several leading structures such as COBIT, ITIL, and ISO27001. Two different aspects must be part of the model: 1) risk management, regarding regulatory aspects; 2) the cost-benefit ratio, related to the company's business process and financial results.

The research in this work was carried out in two phases. In the first phase, a search was carried out with the keywords derived from the initial readings, in works published in journals and conferences. An additional clarification: "CAPES Portal" is a virtual library that brings together and makes available to teaching and research institutions in Brazil the best of international scientific production. In the second phase, some of the main references in the field were analyzed to identify areas of contribution for future research and characterization of the current research. The procedures for each of the phases will be explained during this document. Results of the first phase were obtained by modifying a procedure for the analysis of co-citation of authors, found in the literature [1]. The modified procedure was composed of the steps shown in figure 1, below:

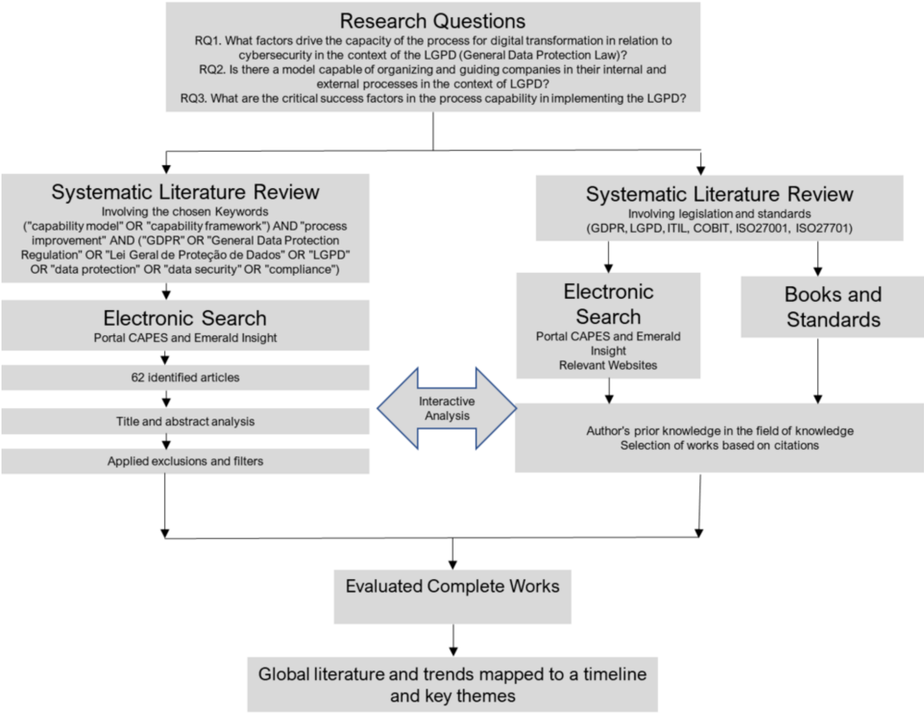

Figure 1. Research Design.

In the second phase, three research axes are established: 1) Capability Model; 2) Processes improvement; 3) Data Protection. After a few searches, the final set of search words, shown in figure 2, was defined.

The reference databases were searched for jobs related to the field informally and loosely. There are two main objectives with this approach. The first objective is to determine whether a keyword generates relevant results. The second objective is to determine whether a specific reference database contains relevant works that include the keyword. The result of the loose screening step is a set of reference databases and a set of keywords to be searched.

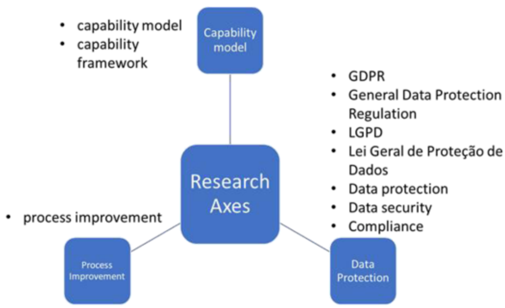

Figure 2. Definitive keywords.

The criteria for selection in the databases were: publication date from 2010 to 2019; Journal articles and English language - as shown in Table 1, for the search engine Portal Capes and Emerald Insight.

Table 1. Literature Review Protocol - Portal Capes and Emerald Insight search engine.

Search words	("capability model" OR "capability framework") AND "process improvement" AND ("GDPR" OR "General Data Protection Regulation" OR "Lei Geral de Proteção de Dados" OR "LGPD" OR "data protection" OR "data security" OR "compliance")	
Boolean Operator	AND, OR	
Database	Portal CAPES, selecting Science Direct Journals (Elsevier), Emerald Insight, Elsevier (CrossRef), Scopus (Elsevier)	Emerald Insight
Language	English	English
Publication Type	Paper from journals	Paper from journals
Period	2010 until 2019 (03/09/2019)	2010 until 2019 (03/09/2019)
Result	40 articles	16 articles

The next step was to download all 56 articles found, to obtain information such as authors, journal or conference, year, keywords, references, and abstract. The interest is also to obtain the full text of the article for further analysis. The records were organized and analyzed to filter duplicate papers and to identify papers that were not related to the subject of our study. This was done by analyzing the title, abstract, and keywords and, when necessary, the full text. The list of works with their records was later exported to an electronic spreadsheet in which they could be treated and analyzed. Twenty-six articles were removed because they are not related to the research theme.

2. Literature Analysis

About future developments that could be derived from the analysis carried out in this work, there are two main areas of contribution to be observed: (i) construction of the model that allows decision making for companies immersed in this context of LGPD and; (ii) the implementation of the model.

Regarding the construction of the model, the main concepts are coming from the following articles: Zou [2] addresses the mapping of the processes for collecting, analyzing, and approving safety information and the communication system. The integration of the ideas of reference structures, capacity maturity models, and improvement processes in the construction of a holistic metamodel [3]. Other industries and applications have not adopted electronic readiness models. However, CMMs, although initiated in software engineering, has progressed to incorporate construction models that encompass processes as diverse as management and financial documentation. Suggests that a CMM is more applicable to applications such as e-commerce in construction [4]. The validation of the cybersecurity structure of socio-technical systems requires time and continuous monitoring in a real-life environment [5]. Support the continued growth of IT-enabled health service models; Compliance with new regulation [6]. Service quality; quality assessment structure is the focus of the study from Domınguez-Mayo [7]. Steuperaert shows the framework for information and technology governance and management [8]. Lack of a common or shared understanding of compliance management concepts is a barrier to effective compliance management practice [9]. The risk concerning the regulatory agency is another subject to be added to the study [10]. The digitalization potential of your business processes [11]. The establishment of clear reference points to allow each agency to determine a roadmap for a greater maturity of electronic contracting [12]. The digital transformation requires the integration of specialized information and communication technology resources [13]. Decision support for IT service managers who want to improve service management processes [14]. The context of multi-regulations with a complex and interconnected information system [15]. The importance of context awareness [16]. Process-oriented developments [17]. Size and sector in the proposed multidimensional model of process capability dimensions [18]. The application of socio-technical systems theory to the domain of information and cybersecurity, where much emphasis is placed on security software and hardware resources [5], To better understand the innovation relationship of IT capacity service from the perspective organizational mechanisms (organizational agility, organizational learning, and entrepreneurial alertness) [19]. Business process management (BPM) is considered the principle of best practice management that can help companies maintain a competitive advantage [20]. Risk management in several selected ISO standards to provide the basis for improving, coordinating, and interoperating risk management activities in IT configurations for various purposes related to quality management, project management, IT service management, and information security management [21]. The construction of process metamodels; the cost of non-quality; budget; Balanced Scorecard perspective; requirements x processes; reactive x proactive models [22].

Concerning the implementation of the model aspects found: Main concepts are that the failure in the implementation occurs due to the maturity of the companies not being taken into account during the definition phase [23]. Classification of relevant issues in the assessment and development of the case for the adoption of the model during the definition phase [24]. Those organizations can choose to structure process improvement projects using various implementations to facilitate the transfer of knowledge within and between units [25]. The motivations, resistances, facilitators, and results of the collaboration [26]. Operational guide for industries to evaluate their distribution processes based on the concept of capacity/maturity [27]. Compliance with new regulation [28]. The introduction of new quality standards can provide the framework for the development and formulation of new innovative business models - the positive view of implementing new regulation [29], and the restrictions or recommendations for the management and performance measurement systems [30][31].

After this analysis, seven main concepts are obtained (A - Business process management; B - Continuous monitoring; C - Standards and best practices; D - New Regulation Compliance; E - Continuous quality assessment framework; F - Risk Analysis; G - Business and context analysis.), which can be grouped in table 2.

Table 2. Seven main concepts.

Author	A	B	C	D	E	F	G
Abdullah (2016)	X						
Balint (2016)	X	X					X
Baraforta (2017)	X					X	
Benmoussa (2015)	X		X				X
Buglione (2013)	X	X			X	X	X
Carroll (2016)			X		X		X
Concha (2012)	X		X				
Cuzzocrea (2019)	X						X
Denner (2018)	X						X
Díaz-Ley (2010)	X	X	X		X		X

Domınguez-Mayo (2015)	X				X		
Eadie (2012)			X	X	X		
Fawcett (2012)	X	X				X	X
Gonzalez-Rojas (2016)				X	X		
Harun (2012)	X		X				
Malatji (2019)					X		
Malatji (2019)	X				X		X
Mayer (2019)				X	X		X
Mc Caffery (2010)				X		X	
McHugh (2012)				X			
Nadarajah (2014)	X		X		X		
Ongena (2019)	X						X
Reyes (2010)	X						
Shrestha (2016)	X				X		
Smart (2010)	X	X			X		X
Steuperaert (2019)			X	X			
Tsou (2018)			X				
Van Looy (2018)							X
Van Looy (2019)	X						
Zou (2017)	X	X					X

3. Additional Literature

The acronym COBIT stands for Objectives Control for Information and Related Technology. It is the most recognized and used knowledge base in the market to support organizations in Information Technology Governance (IT) [32].
COBIT 5 is based on 5 principles that create a kind of direction for the system of governance and management of information and related technology used within an organization [32]. The 5 COBIT principles are: Principle 01 - Meet the needs of stakeholders; Principle 02 - Cover the organization from end to end; Principle 03 - Apply a single and integrated framework (model); Principle 04 - Allow a holistic approach; Principle 05 - Distinguish governance from management.

ITIL is an acronym for Information Technology Infrastructure Library; it is a set of detailed best practices for IT service management that focuses on aligning IT services with business needs [33]. ITIL describes processes, procedures, tasks, and checklists that are neither organization-specific nor technology-specific but can be applied by an organization to establish integration with the organization's strategy, delivering value and maintaining a minimum level of competence. It allows the organization to establish a baseline from which to plan, implement, and measure. It is used to demonstrate compliance and measure improvement. There is no independent third party compliance assessment available for ITIL compliance in an organization [33].

ISO standards are based on the concept of Management System, that is, how activities are coordinated to direct and control an organization with its objectives. That is how activities are organized, carried out, and supervised to achieve a specific objective (ISO).

ISO / IEC 27001: 2013 [ISO / IEC 27001: 2013] Information technology - Security techniques - Information security management systems. It specifies the requirements to establish, implement, maintain, and continuously improve an information security management system in the context of the organization. It also includes requirements for the assessment and treatment of information security risks, adapted to the needs of the organization. The requirements established in ISO / IEC 27001: 2013 are generic and must apply to all organizations, regardless of type, size, or nature [34].

ISO / IEC 27701: 2019 [ISO / IEC 27701: 2019] - Security techniques - Extension to ISO / IEC 27001 and ISO / IEC 27002 for privacy information management - Requirements and guidelines. This document specifies requirements and guides establishing, implementing, maintaining, and continuously improving a Privacy Information Management System (PIMS) in the form of an extension of ISO / IEC 27001 and ISO / IEC 27002 for managing privacy in the context of the organization. Besides, it specifies the requirements related to PIMS and guides personally identifiable information controllers (PII) and PII processors responsible and responsible for PII processing. This document applies to all types and sizes of organizations, including public and private companies, government entities, and non-profit organizations, which are PII controllers and PII processors that process PII within an ISMS (Information Management System) Information Security) [35].

4. Components of the Preliminary Conceptual Model

Any changes to the company's structure or service processes would have a direct or indirect impact on customers and stakeholders (including regulatory authorities). However, it depends on what those changes are. The response to the regulatory context may be a risk or an opportunity since the National Data Protection Agency (ANPD) has not yet regulated some aspects of the law. There are two main areas of contribution to be observed: building the model that allows decision making for companies immersed in the LGPD context and; (ii) the implementation of the model.

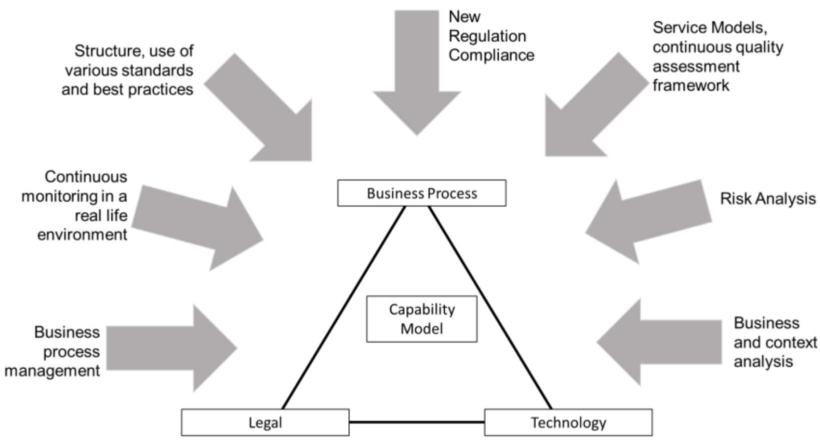

Figure 3. Main components of the model.

Thus, derived from the analysis the main components of the model and preliminary that we see are (shown in figure 3): 1) Business process management; 2) Continuous monitoring in a real-life environment; 3) Structure, use of various standards and best practices; 4) New Regulation Compliance; 5) Service Models, continuous quality assessment framework; 6) Risk Analysis; 7) Business and context analysis.

Capability is the ability to perform a repetitive pattern of actions that is necessary to create value for the customer.

A business capability is a fundamental element of what a company does or can do. It is an abstraction of the functionality and the underlying flows expressed as a substantive form. An agglomeration of a cluster of underlying business resources can manifest a product, service, platform, business unit, department, and, of course, a company.

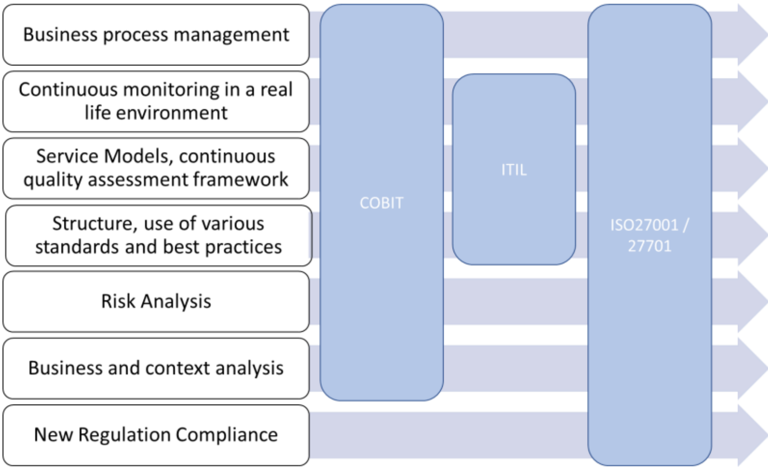

Figure 4. Main components of the model related to the additional literature.

Figure 4 shows the main components of the model related to the additional literature. A capability model (or business capabilities map or capabilities model) is a structurally sound and internally logical group of capabilities; this main components will be the base for the following steps that are being constructed at the doctorate thesis of the author (figure 5).

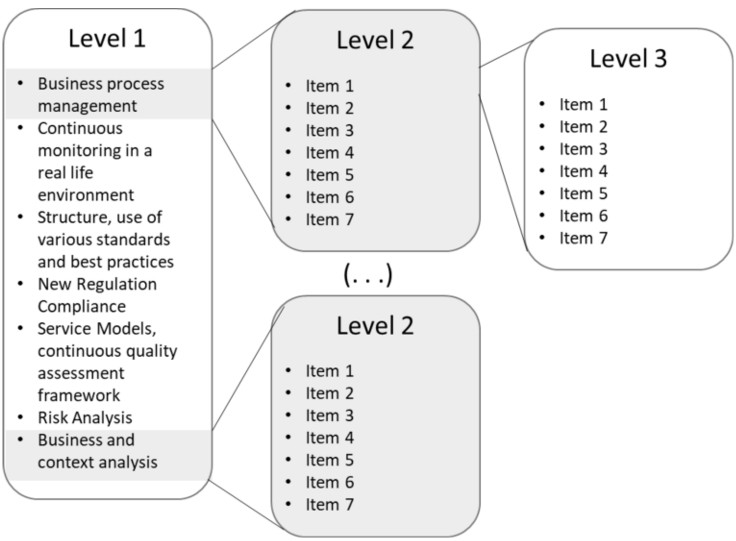

Figure 5. Generic structure of the future capability model.

5. Conclusions

The main objective of this work was to present the main components of the future capability model to understand the functionality and the underlying flows in the LGPD context. Research lines were found to go in different directions, being aligned with the research problem explicitly related to the General Data Protection Law (LGPD), which provides us with a field of action to be explored. In any case, existing research supports the construction and implementation of decision-making models. Thus, the main components of the future capability model we see are: 1) Business process management; 2) Continuous monitoring in a real life environment; 3) Structure, use of various standards and best practices; 4) New Regulation Compliance; 5) Service Models, continuous quality assessment framework; 6) Risk Analysis; 7) Business and context analysis.

Taking into account the complementary concepts of the good practices already used today, the model will evolve with the concepts of COBIT, ITIL, and ISO27001 / 27701. COBIT brings the direction for the system of governance and management of information and related technology used within an organization. ITIL has focused on aligning IT services with business needs. ISO shows the concept of Management System - how activities are coordinated to direct and control an organization concerning its objectives.

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Practice-Based Learning as Lever for Successfully Adapting Supply Chain 4.0 Technology: Foreground People

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Abstract. SCM 4.0 is expected to lead to increased automation and transparency throughout the supply chain; thus, opportunities for operational efficiency and digital enabled business models [1], [2]. However, the SCM 4.0 impacts the decision-making towards higher complexity [3]. Technology-wise many companies have adapted SCM 4.0. This paper claims that organizational and leadership matters have not yet gone through similar transition; Actually, we can neither see any changes in the way companies organize supply chains nor in how they facilitate practice-based learning of employees and leaders. With SCM 4.0 technologies, an effective supply chain is not just a question of transforming components to finished goods. Rather, the contemporary SCM organizations need a strong transdisciplinary practice-based learning agenda to be able to deliver customer value [4], [5]. With the purpose of understanding transdisciplinary levers for practice-based learning in SCM, the study builds on two cases of implementation of SCM 4.0 technologies, exploring how the case companies have managed the transformation from a classic 2.0 to a 4.0 practice-based learning organization. The research question guiding the study is: to what extent can practise-based learning be a lever for adapting SCM 4.0?

Keywords: SCM 4.0, learning supply chain, practise-based learning

Introduction

Industry-wide, supply chain management faces the challenges from new digital technologies known as Supply Chain 4.0 (SCM 4.0) [6], [7]. The transformation to SCM 4.0 is expected to lead to increased automation and transparency throughout the supply chain; thus, opportunities for operational efficiency and digital enabled business models [1], [2]. The new technologies (SCM 4.0) impacts the decision-making towards higher complexity [3]. This paper claims that organizational and leadership matters have not yet gone through similar transition; Actually, we can neither see any changes in the way companies organize supply chains nor in how they facilitate practice-based learning of employees and leaders.

Supply Chain 4.0 sets the agenda for a digitised transformation of Supply Chain Management (SCM). Digitalization of SCM, entailing integration and transparency of data and information enables new opportunities for operational efficiencies, sustainability and new business models. [8], [6]. SCM 4.0 builds on the fourth industrial revolution – also named as Industry 4.0. [7]. The scope is the integration of the factory with the entire product lifecycle and supply chain activities. This is predicted to change the way people work. [7], [1], [6]. Digitalisation of supply chain can be seen as "a radical

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change in products and services, processes, or entire business models through the application of digital technology” [6].

The transition from SCM 2.0 to SCM 4.0 seems to be fuelled by the development of new digital tools for integration in information flow and decision support, as well as automation of processes. The transition escalates both the pace of changes and in particular the complexity of the decision making in the supply chain [7], [1], [6], [2]. With SCM 4.0 technologies, more data will be available for decision making. However, data needs context and reflection to become knowledge. Effective supply chain management is not just a question of transforming components to finished goods. Rather, the contemporary SCM organizations need a strong transdisciplinary practice-based learning agenda to be able to deliver customer value [4], [5].

In the beginning of year 2000, the supply chain complexity was the effect of globalization, e.g. having manufacturing placed in overseas areas (Asia) and markets in Europe, USA, etc. In 2020 the complexity in supply chain is still coming from the dispersed supply chain structure. However, also from the quest for digitalization. The increased volume of data to be handled, increased number of relations to be managed, is making prediction of what is going to happen e.g. forecasting demand, a difficult task. This increased complexity can lead organizations and people to a “lock-in” where there is no decisions and no actions, as we drive our supply chains based on the year 2000 habits, in a business and organisational context that is much more complex. To solve this leadership dilemma there is a need to develop a learning organization that can adapt to the new complexity from SCM 4.0. With the purpose of understanding transdisciplinary levers for practice-based learning in SCM, the study builds on two cases of implementation of SCM 4.0 technologies, exploring how the case companies transform from SCM 2.0 to SCM 4.0 using practice-based learning as a lever.

The research question guiding the study is: *to what extent can practise-based learning be a lever for adapting SCM 4.0?*.

1. SCM 4.0 and Learning

To understand the complexity in organisation and leadership in the SCM4.0 era this section will explore SCM, SCM4.0 and digitalization as well as practise-based learning.

The notion of a supply chain has been known for nearly 40 years [9]. Most definitions seem to revolve around three elements 1) the network structure, 2) the business processes and 3) management components. This definition has been widely used *"A network of connected and interdependent organizations mutually and co-operatively working together to control, manage and improve the flow of materials and information from suppliers to end users"* [10, p. 19]. A similar definition [11] of SCM states that it is about integration of key business processes from end user through original suppliers that provides products, services, and information that add value for customers, and other stakeholders. SCM includes both up- and downstream activities respectively focused on supply and manufacturing and logistics and distribution. Most models used to describe a supply chain is highly structural. The scope of the models is the material flow, how to balance inventories, cost optimize the supply chain, re-engineer the business processes etc. [11], [12], it is very rare to find people, learning and leadership in the supply chain models and concepts.

A successful supply chain depends on the integration of the value chain entities in order to create a collaboration that facilitates the exchange of information, materials and cash flows [13]. Both in practice and in academia, the main focus is optimization of the flow of information and material, sourcing channels and planning concepts of various kinds to deliver good customer service.

Industry 4.0 or SCM 4.0 is the latest development stage in the industrial development. The first industrial revolution (Industry 1.0) was in the end of the 18th century when manufacturing was powered by steam engines. The second industrial revolution in the start of the 20th century, I2.0 – was when electricity could be used to power machines in production [7], [1], [2]. This gave a high flexibility of manufacturing e.g. regarding layout. The third industrial revolution was in the 70ies by the introduction of the computer and first cases of automation. This led to the current concept of Industry 4.0. The drivers behind I4.0 can be seen as a demand pull, i.e. customers requesting fast service, short delivery time, more individualized products etc. and a technology push through new opportunities for automation of manufacturing processes and administrative processes, information integration across the supply chain creating transparency. SCM 4.0 can be defined as “A supply chain which involves close collaboration of different stakeholders (e.g. suppliers and customers) and is built on digital technology, including but not limited to, web-enabled technology, cloud computing and Internet of Things” [8], [14].

The global logistics company DHL is on a yearly basis updating a “Logistics trend Radar” [15] where a map is created of the state of development, in technologies and social/business trends against their likelihood to make disruptive impact on logistics (supply chain) and against an impact timeline of under/over 5 years. Examples of technologies are IoT-Internet of Things that is expected to have an impact on logistics in less than 5 years and have the potential to connect anything to the internet and accelerate the data-driven logistics. In the other end of the scale we have Self-driving vehicles. This is expected to have impact in more than 5 years. On social and business trends we find examples of a trend that is expected to have high disruptive impact in 5+ years is named as “supergrid logistics” [15]. This is described as going beyond 4PL logistics and raise a new generation of logistics companies with primary focus on the orchestration of global supply chain networks that integrate different production enterprises and logistics providers [8]. All the emphasis is on the use of digital technology to transform supply chain (SC) operating models [6], identifying new ways to service the customers, places considerable emphasis on the ability of the individual, the organisation and the company to learn and to continue to learn to keep pace with the development.

Taking a second look at the DHL trend radar, the human side of supply chain management is missing. Likewise, literature and cases on SCM 4.0, [1], [16], [2] have a fascination for the technology development, using AI, IoT, Robots of different kinds etc. to optimize the flow of goods and the speed of information and decision making in supply chain. However, learning is also instrumental in driving efficiencies in supply chain.

Until recently the "soft" side of the supply chain, the managerial and behavioural, management methods, power and leadership structure, culture and attitude have been deprioritized for the fascination of technology and structures i.e. an engineering approach. In a survey in Danish industry [17], one of the significant barriers to implementation of SCM 4.0 was that it “Requires continued education of employees” and “Lack of employee readiness” [17, p.130]. This points at learning as a lever for supply chain organizations to be ready for implementation of SCM 4.0 technologies.

The American philosopher, educator and psychologist John Dewey (1859 – 1952) develops the theory of: "Learning by doing" [18, p.57]. Dewey is inspired by pragmatism and how psychology could be used in practice. For Dewey, training is a prerequisite for development [20], and learning processes must have a goal, a higher ethical societal objective. Dewey was critical of learning from a spectator perspective, to learn a person needs to be engaged - you do not become a good football player by watching from the sideline.

For Dewey, learning was "about becoming and growing as a human being, as culture and as a society." [20, p. 85]. Dewey focus on the fact that experience and education as a method are the starting point for realization and thus learning. A central concept for Dewey is "inquiry" [18]. According to Dewey, we must understand the concept of inquiry broadly, as study or experimental actions [18]. We are constantly in situations where we need "to conduct further studies and experiments" [18, p. 56]. Inquiry means that we make assumptions that we subsequently test, clarify and reformulate. Dewey's learning concept is based on learning being created in practice, but learning does not come automatically from experience, but it is necessary to combine activity and reflection to achieve learning [19]. Dewey focused on learning happening in social contexts, for example an organization as a “learning field”, through the interaction in a workplace [18]. Learning can be done in situations of solving concrete problems, which leads to "learning-by-doing".

Another contribution to learning theory is the American psychologist Donald A Schön (1930-1997), who has conducted studies on how qualified employees think and act in practice. Central to Schön is the link between "thinking, reflection, action and learning" [22, p. 254]. Schön defines two key concepts - knowledge-in-action and reflection-in-action. Knowledge-in-action is found in what Schön calls intelligent actions, e.g. in riding a bike. Knowledge is in the action and is revealed through the action [22]. We are often unable to explain our action with words, we just do it. Knowledge-in-action usually takes us through everyday life. However, when a well-known action leads to an unexpected result. An error does not resolve itself by the usual method, we are surprised about the outcome of an event [22]. There's something that doesn't happen as expected. This is where Schön introduce the second central concept of reflection-in-action.

Where knowledge-in-action is silent, spontaneous, carried out unconsciously and works as long as the action gives the intended result and the situation falls within what has been learned as being normal. Reflection-in-action is going on while acting [22]. Even our routine tasks can lead to surprise and thus to reflection-in-action. We reflect on the unexpected with questions like, "What is this?", "How have I really thought about it?" [22, p. 259]. Reflection-in-action has the important feature, to be critical of knowledge-in-action and challenge the built-in thinking. Reflection allows you to perform test actions and experiment while the action happens. New actions are being tested for new and better practices and thus leading to knowledge-in-actions [22]. When there are situations in practice that do not suit the learned (knowledge-in-action) then through reflection-in-action the individual has the opportunity to form new knowledge.

2. Methodological considerations

With reference to the different definitions of supply chain management [9], [11], [12], [23], SCM is cross functional and cross disciplinary of nature. SCM research have for many years been influenced by an engineering and economic approach. However, [24] calls for a pragmatic approach vs the traditional positivist approach to supply chain research and knowledge creation. In supply chain research there seems to be a primary use of quantitative methods [25]. Given that supply chain management is a complex, cross disciplinary research area [26] the use of qualitative data is important for uncovering the people (social) related elements of a supply chain.

The approach of abduction stems from pragmatism [26]. The father of pragmatism Charles Sanders Peirce (1839-1914) [21], pointed out that we create new knowledge "when our existing knowledge and habits prove insufficient to explain and understand a new experience" [21, p. 175]. Pragmatism is also connected to John Dewey (1859-1952), the founder of "learning by doing". As a pragmatist, Dewey was concerned with "solving problems in current societal practices". [20, p. 77].

This paper will build on the call for applying the pragmatic explorative approach – abduction [24]. During the analysis we will explore the empirical data – let the empirical findings talk - and based on the patterns we see; new findings will surface. Data for the paper is secondary data, and not directly generated for the paper. However, questions investigated and findings support the topic of this research. Case data is generated through two interventions with two different groups of supply chain leaders.

Case A generate data through a three-hour workshop with a group of senior supply chain leaders, having focus on opportunities to optimize the end to end supply chain by application of SCM 4.0 technologies. The participants are all at VP level, factory directors, head of S&OP etc. the workshop started with a recap of what constitutes a supply chain, creating a common understanding of the theory foundation for supply chain management, and SCM 4.0. Based on this, basic learning theory was introduced, and through interactive Q/A sessions learning was related to the actual daily day of the participants, to provoke reflections on how the participants lead and learn from what they do in practice. Data was recorded as notes from the discussions, flip overs from group work containing the participants reflections on training vs learning and where they could see opportunities to do more in the current supply chain, by focusing on learning and not only training, as levers for the digital transformation of the supply chain.

Case B investigates the transformation to SCM 4.0 in six SME (Small-Medium size Enterprises) companies, seen from the perspective of the senior leaders – COO / CEO level. Data was generated through a two-hour focus group interview centred around how the SME organisations implement new SCM4.0 technology and investigating if there are traces of learning in the way of working and to what extend learning works as a lever for the SCM 4.0 implementation. Data is generated based on researcher notes and a recording of the focus group interview. The recording was not transcribed, only used as support in cases of doubt on the actual dialogues and points at the meeting. The participants have roles spanning from Owner, Board member, CEO/COO, head of business development. All six leaders have hands-on experience and responsibility for operations and supply chain of the companies. Two major stories are highlighted in the case description for illustration of the link between implementation of SCM 4.0 technology and learning in the organization.

3. Case A – SCM 4.0 transformation in a large food supply chain

This case is about a large company in the food industry with a global supply chain, having operations in more than 100 countries, and approximately 20.000 employees globally.

Through the workshop with the senior supply chain leaders they were challenged on how they learn, how their organization learn and train. From this, small stories were found that illustrates how the senior managers work with the transformation of the supply chain to a SCM 4.0. Strategically the company has focus on innovation of new products with a purpose of doing good for the public health. The leadership of the supply chain has started a digitalisation transformation to SCM 4.0.

Operating in the food industry the company must comply with a strict set of rules and regulations, on health and safety. To make sure to comply with the regulations, the company have fixed training schedules for specific functions and roles in the organization. In addition to the training schedules, a cross the supply chain organization they excel in traditional lean tools and ways of working, 5*why, fish bone diagram for problem solving etc.

The reflection from the senior managers on the current practise is that there they do not share their own practise or have formalised reflection on practise, even in the leadership team forum. Focus for the training and follow up activities are all related to operations issues and performance follow up. The leadership team explains that it is difficult to address ways of working and have time to reflect on practice as this behaviour is not rooted in the leadership practise. One of the statements from the workshop was "why don't we ever ask why? – when the performance is green?". The story behind the question is that the supply chain leaders are highly focused on the performance KPIs, where expected performance is not met (red KPI). However, in the actual case of green performance, the leaders do not create space for reflection on what is working really well in the supply chain, and take the learnings from this into other processes and functions.

The SCM leadership team also discussed what would be the difficulties of implementing new SCM 4.0 technology in the supply chain, and the current practise of training and learning. As part of the digitalization efforts the company have analysed strength and weaknesses regarding implementation of specific digital technologies like BI (Business Intelligence) for improving the transparency of the supply chain performance, IoT in monitoring and tracking of products and trucks in distribution, Robotic Process Automation – RPA to automate ex. planning processes. The company already have experience with RPA in finance processes (invoice control etc.).

The company see RPA as having many more opportunities for improving supply chain processes. However, the company is facing a challenge of quality of master data. For the investigated processes in the supply chain there is a poor data discipline, resulting in employees losing trust in the data. This is a paradox; on one hand the company have a lot of supply chain data available but having a low data validity. The issues with data quality are rooted in a landscape of different not integrated systems, this challenges the organisation ability to optimize operations.

The SCM leadership team finds that the organisational ability to learn from practise and optimise processes is a key driver for being able to utilize SCM 4.0 technologies.

4. Case B – SCM 4.0, technology implementation and learning in SME companies.

This case investigates the transformation to SCM 4.0 in six SME companies, seen from the perspective of the senior leaders – COO / CEO level. Data is generated through a focus group interview with the six senior leaders from the SME companies. The participants have roles spanning from Owner, Board member, CEO/COO, head of business development. All six leaders have hands-on experience and responsibility for operations and supply chain of the company. The focus group participants are all part of a network group in the printing industry. The network group was established in 1987 and have therefore a long history on the technology development in the printing industry and also the network group have a high trust level and are able to discuss complex leadership issues. Two major stories are highlighted here for illustration of the link between implementation of SCM 4.0 technology and practise-based learning.

The focus group interview was centred around how the SME organisations implements new SCM4.0 technology and investigating if there are traces of learning in the way of working and to what extend learning works as a lever for the SCM 4.0 implementation. Through the focus group interview small stories was found that illustrates how the senior managers work with technology implementation. An example is one of the participants explaining how a new automated machine in the printing production, delivered a poor-quality output and how the leadership team and the operators structured in the search for solutions. In this chase the team sorted all errors from the machine and coded the poor-quality samples and based on this build knowledge about the process in the new automated machine that led to new solutions.

Another story from one of the participants is based in the logistics part of the printing supply chain. The company experienced that a new SCM4.0 online transport booking platform, changed the processes for the drivers and their connection to the customers. Before the new booking platform, the drivers were in direct contact with the customers. However, the new platform was automating the information flow between customers and drivers and the company experienced that errors e.g. missing information in labels, packaging not suitable for transport etc. that previously was handled by the drivers, now, because of the changes in process based on the new booking platform with no interaction between customer and driver, was suddenly issues that could jeopardize the shipping of the products.

5. Analysis and discussion

Based on the two cases the analysis and discussion will explore how practise-based learning can support the transformation of a supply chain into a version 4.0 digital supply chain. We are curious to see if we can find traces of learning from practise like defined by Dewey, “learning-by-doing” and “inquiry” [19], or “reflection-in-action” to “learning-in-action” [22] as the foundation for the supply chain organisation to cope with the transformation to a digital supply chain (SCM 4.0).

In case A, the supply chain leadership team, discussed the different ways of training in the supply chain, and found that they have many different training courses and also, they have formalized apprenticeship forms of on-the-job training. All of the trainings were found to be rooted in the ability to master a tool e.g. a lean process tool like 5*why, fish bone diagram for problem solving etc. this way of training looks at first like Dewey´s “learning by doing”. However, an important element of the learning practise from Dewey is the “inquiry”. This is where the individual asks the - why does this happen as it is?. Listening to the SCM leaders in case A, this inquiry on the process does not happen systematically. This also points at the learning based on Schön [22], the reflection is not happening, this means that the organization does not systematically create new knowledge based on the practise.

Challenging the leadership team in their own practise the reflection is that they do not have a structured practise of reflection on practise, like described by Schön [22] and the leadership team do not create new knowledge from their practice. The missing structed learning approach is also seen in the issues of supply chain master data quality, where lack of reflection on practise is leading to missing actions on improving the master data quality, and this is critical as high master data quality is a precondition for digitalisation of the supply chain and using the SCM 4.0 technology of RPA to optimize supply chain business processes.

In case B we found two stories of implementation of new technology in the SME supply chain. The first case was implementation of a new automated production process. Here we found that the leadership team used a highly structured approached to the challenge of getting the new automated process to work. This support the learning process described by Schön [22], reflection-in-action leading to knowledge-in-action. The structured approach to the automation challenge points at a leadership team involving the full supply chain in the learning process.

The other example from case B is the implementation of a new SCM 4.0 online transport booking platform. The changes to processes lead to the truck drivers need to learn a new way of working. During the implementation the reflection on the business processes and ways of working reviled that the new booking platform was not the most important issue for the drivers. The inquiry into the new processes (Dewey) [19], showed that it was the quality of packaging provided by the customers that was the most important issue to solve to secure the success of the new SCM 4.0 online transport booking platform.

6. Conclusion

The research question guiding the study is: *to what extent can practise-based learning be a lever for adapting SCM 4.0?* To answer the question, we have built on the call for an abductive approach [24] to knowledge creation by outlining the two cases of supply chain transformation to SCM 4.0, searching for stories that points at the use of practise-based learning.

Taking a people focus on the development of SCM 4.0 we found that it has a historic link to the industrialization in the beginning of the twentieth century. Until recently the "soft" side of the supply chain, have been deprioritized for the fascination of technology and structures. This is giving a challenge when transforming from SCM 2.0 to SCM 4.0. The current supply chain models do not capture the complex leadership task of a supply chain 4.0 [5]. This is also indicated by a supply chain survey in Danish industry [14] which points at learning as a lever for supply chain organizations to be ready for implementation of SCM 4.0 technologies.

The two cases both show traces of practise based learning, learning by doing, inquiry, and reflection in action to knowledge in action. Also, the cases show that learning can be a lever for adapting SCM 4.0 technologies in a traditional supply chain. Another finding from the cases is that the organisational ability to learn from practise and optimise processes is important for being able to utilize SCM 4.0 technologies. However, we find that this is not systematically happening. There seems to be little awareness on learning in practise. The “muscle” of reflection and inquiry is untrained – at best it is mechanical – “5S” exercises and solving of operational issues.

In supply chain, learning is often translated to training in many different shapes and forms. To help the transformation of supply chain practise from SCM 2.0 to SCM 4.0, companies need to develop a conscious and systematic learning practise. A few leadership practise steps in this direction would be, based on Dewey [19], [20], to create room for experiments and reflections on current practise, to cultivate psychological safety in the organizations [27], and to develop a practice of systematically giving feedback on behaviour and performance, this would be baby steps towards building a supply chain learning culture.

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Will Enterprise Ownership Affect the Performance of Foreign Direct Investment？Based on the Perspective of Institutional Logic

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Abstract. In recent years, Chinese enterprises have been developing rapidly with the encouragement of the “Belt and Road” initiative, setting off a new wave of direct investments in foreign. On the stage of global trade competition, one of the biggest differences in companies between Chinese and Western lies in the forms of enterprise ownership. Does enterprise ownership have an impact on the performance of direct investment in foreign? This study takes the inter-provincial panel data of 571 listed companies in China from 2014 to 2017 as a sample. Based on the practices and characteristics of Chinese enterprises' direct investment in foreign, we use a institutional logic perspective to explore the impact of enterprise ownership on performance of the investment. The study found that non-state-owned enterprises perform better in the investment; state-owned enterprises have more resource-seeking Chinese enterprises' foreign direct investment (OFDI), while non-state-owned enterprises tend to choose market-seeking OFDI; market-seeking OFDI has better performance than resource-seeking and technology OFDI performs better. The research proves that the corporate ownership has an impact on the performance of the investment. The conclusions of this paper are helpful to adjust national policies as well as provide a reference for Chinese enterprises in decision marking from institutional perspective.

Keywords. Institutional Logic, Enterprise Ownership, OFDI, Enterprise Performance

Introduction

Will enterprise ownership affect the performance of the enterprise's foreign direct investment? The impact of ownership on enterprises is a key issue in China’s strategic research field, because it determines the correct internationalization strategy and the appropriate degree of internationalization, and provides guidance for enterprises on how to choose their own internationalization strategy and global layout. This research is driven by reality. Since the implementation of the "Going Global" strategy in 2001, Chinese enterprises' foreign direct investment (Hereinafter referred to as OFDI) has grown rapidly, and the overall upward trend is obvious, occupying the top three positions in the world for seven consecutive years. An analysis of the characteristics of China’s dominant state-owned enterprises and increasingly active private enterprises in

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their outward direct investment behavior will undoubtedly be the entry point for a comprehensive and in-depth understanding of China's outward direct investment.

In the current academic world, there is much room for improvement in terms of sample size, research depth, and breadth. Existing scholars have conducted theoretical and empirical studies on China's OFDI motivation [1], the relationship between the degree of internationalization of enterprises and performance [2], etc., and have achieved certain research results, but it is worth noting that: Some studies have yet to be perfected in terms of research perspectives and measurement indicators of institutional factors.

This article attempts to explore and verify the direct and regulatory mechanism of corporate ownership on the enterprise from the perspective of institutional logic, and how institutional logic affects corporate performance and competitive advantage. By using the perspective of institutional logic to deeply analyze the complex impact of the Chinese context on corporate FDI decisions, it contributes to the academic community.

1. Institutional logic

Institutional logic is a research method that emerges at the new stage of new institutionalist theory. It is related to a series of material practices and symbolic structures, driving and constraining the behavior of social actors and shaping behavior [3]. One of the basic assumptions is that different institutional logics will lead to different decisions and behaviors [4].

The current research on China related to institutional logic mainly focuses on the changes in the dominant logic during the "plan-market" transition period. Numerous studies have shown that in China, companies are mainly influenced by the two dominant logics of national logic and market logic [5-9]. National logic and market logic are very different in nature: The goal of national logic is to protect the overall interests of society. It is to emphasize the basic direction of the country in ensuring social and political order, and to create a series of rules and meanings to set up an institutional framework for the environmental behavior of enterprises; The market logic is to form a normative and cultural understanding through property rights arrangements and transactions. All parties to the transaction pursue maximum private benefits through free competition, emphasizing that corporate behavior is mainly driven by their own interests. In the more than 30 years since the reform, through the interaction of different social forces, China has gradually formed a situation in which the two logics of state logic and market logic coexist and influence each other. The historical stage of rapid economic development and rapid system changes has made enterprises often face an extremely complex and changing system environment.

Among state-owned enterprises, the influence of national logic is strong. Xia Lijun and Fang Yiqiang believe that the government has the greatest influence on state-owned enterprises [10]. On the one hand, for enterprises with strong government control, the government has the motivation and ability to internalize the country's overall policies into the controlled enterprises. For example, the government requires enterprises to invest in the country. Due to the scarcity of enterprise resources, Large domestic investment will affect the level of foreign investment of enterprises, which will make enterprises lose the opportunity to participate in foreign direct investment. On the other hand, corporate executives are subject to a higher degree of government administrative restrictions, which allows the government to communicate its policy on foreign direct investment to corporate decision-makers, and decision-makers will use this policy as the primary reference [11].

Non-state-owned enterprises mainly display market logic, clear property rights, single business objectives, and the pursuit of maximizing corporate profits. Non-state-owned enterprises, as an important force to promote my country's economic development, have been actively implementing the "going out" strategy in recent years. Based on the domestic basis, they expand foreign direct investment, use multiple investment methods such as cross-border mergers and acquisitions, joint ventures, etc. to combine their own operating advantages with various advantages in the host country market to form their own unique integration advantages, which greatly improves the enterprises' Competitiveness.

2. Outward foreign direct investment (OFDI)

The study found that China's OFDI development has its own unique model. Child & Rodrigues believes that most of China's foreign investment decisions will succumb to the requirements of national will or macroeconomic interests, which is different from the goal of private companies to maximize profits, resulting in their investment flows will not be based entirely on the general laws of international capital flows , Which in turn will cause China's OFDI decision-making to be different from other countries. On the basis of reading and summarizing the research of scholars, this article classifies foreign direct investment behavior as follows:

- Resource-seeking OFDI.

  The resource-seeking OFDI guarantees the effective supply of domestic resources by controlling foreign resources [12]. This behavior has a certain national strategic intention. Resource-seeking OFDI requires investment approval of the home country and host country, and carries certain political risks, legal risks, cultural risks, and market risks. In addition, the host country's review standards are ambiguous, the actual implementation process is highly operable, the approval is strict and the cycle is long, and the requirements for the scale, capability and risk tolerance of the enterprise are high. These requirements have hit the enterprise's resource-seeking type to a certain extent. The motivation of OFDI [13].
- Technology-seeking OFDI.

  Technology-seeking companies track the latest trends in the industry by establishing R&D centers in technologically advanced regions or acquiring host country R&D teams in the form of mergers and acquisitions, understanding competitors in technology-intensive regions, accumulating human resources, and improving their comprehensive capabilities [14][15][16]. Technology-seeking OFDI can increase an enterprise's internal capabilities, enhance its core competitiveness, promote its industrial upgrading, and give it a comparative advantage in internationalization [17].
- Market-seeking OFDI.

  Market-seeking OFDI refers to companies seeking overseas markets and selling excess products abroad to increase their profits [18]. The market-seeking OFDI must consider the host country's market size, competitors' situation, consumption level, consumer preferences, as well as the company' s own size and flexibility.

3. The Relationships between enterprise ownership and performance

How are the performance of state-owned enterprises' OFDI affected? In the process of OFDI of state-owned enterprises, the Chinese government often provides support or guarantee at the level of policies and systems. State-owned enterprises enjoy policy benefits such as subsidies, credit, taxation, and supervision. However, state-owned enterprises also face a lot of problems when making OFDI: firstly, state-owned enterprises need to respond to the national call and consider the overall welfare of society, including diplomatic, economic, energy security and resource security factors, and secondly consider their own profits [19]; Secondly, the lack of crisis awareness and competition concept, and the lack of clear purpose and orientation of state-owned enterprises' direct investment abroad, which led to the state-owned enterprises' investment in the host country's economic environment, legal environment and investment prior to their direct investment abroad The lack of sufficient inspection and evaluation of information such as the legal system, to a certain extent, may inhibit the improvement of the operating performance of state-owned enterprises. Finally, the state encourages state-owned enterprises to tap and utilize the innovative resources of developed countries with a more positive attitude. Because of this, overseas mergers and acquisitions of state-owned enterprises are more likely to be resisted or obstructed by the host country [20][21].

What are the advantages and disadvantages of OFDI by non-state-owned enterprises? Non-state-owned enterprises with clear property rights have greater operational autonomy when making OFDI, and can make scientific investment decisions based on the interests of the enterprise and market-oriented. At the same time, less policy intervention is also conducive to exerting its internal advantages and realizing economies of scale. The main difficulties for non-state-owned enterprises are: First, non-state-owned enterprises lack financial support. The funds for a country's overseas investment mainly come from the country's National Export-Import Bank, while my country's Export-Import Bank loans mainly support overseas investment projects undertaken by large and medium-sized state-owned enterprises. Second, my country's non-state-owned enterprises are generally small in scale. According to statistics, 73% of private enterprises have annual sales of less than RMB 2 billion, of which 64% have a profit of less than RMB 100 million. However, in comparison, non-state-owned enterprises have more advantages in OFDI than state-owned enterprises.

The analysis based on our data also supports our hypothesis: the performance of non-state-owned enterprises is higher than that of state-owned enterprises [22].

4. The relationships between OFDI and enterprise performance

As China's economy continues to develop, China's demand for resources is increasing, but domestic resource reserves are limited. After years of extensive mining, domestic resources have been unable to meet the needs of economic development (Ramasamy, 2012). Resource-seeking ODI is crucial to China's overall economic development. The

probability that the market-seeking OFDI is subject to review by the host government is mainly determined by the willingness of the enterprise. This involves the company's preliminary investigation and evaluation of the host country's overall operating environment, the company's ability to withstand risks, and the company's expectations for market prospects, sales volume increases, marginal costs, and corporate profits. The market-seeking OFDI of enterprises mainly revolves around reducing costs and increasing profits for enterprises. Compared with resource-seeking OFDI, market-seeking companies perform better.
Two other assumptions:

- The technology-seeking OFDI has better performance than the resource-seeking OFDI.
- The market-seeking OFDI is better than the technology-seeking OFDI.

Data research results show that the impact is not significant.

5. Conclusion

By using the inter-provincial panel data of 571 listed enterprises from 2014 to 2017, this paper conducts an empirical study, and finds that:

1. in OFDI behavior, non-state-owned enterprises perform better than state-owned enterprises;
2. some Chinese enterprises will choose resource-seeking OFDI;
3. non-state-owned enterprises will choose market-seeking OFDI;
4. the performance of market-seeking OFDI is better than that of resource-seeking OFDI.

State-owned enterprises are much larger than non-state-owned enterprises in terms of enterprise size and financing level, and are more inclined to resource-seeking OFDI. Most non-state-owned enterprises have weak risk tolerance, and are more inclined to purchase and imitate technologies, and to carry out technology-seeking OFDI. In order to get rid of the disadvantage of partial saturation of the domestic market, non-state-owned enterprises will resort to OFDI to seek overseas markets and actively pursue market-seeking OFDI. In resource-seeking OFDI, Chinese enterprises encounter many uncertainties. For example, the government of the host country takes too long to review, leading to the high cost of waiting time for enterprises, and missing the opportunity of resource production, resulting in the high production cost of enterprises. The cost of resources acquired by enterprises through OFDI is generally high, and resource-seeking OFDI has little impact on the improvement of enterprise performance. The performance of market-seeking OFDI is higher than that of resource-seeking OFDI.

This paper studies the relationship among enterprise ownership, OFDI behavior and OFDI performance from the perspective of institutional logic, and selects data from the enterprise micro level as the measurement sample. Academically, it complements the research in this field. In practice, it provides reference Suggestions for promoting Chinese enterprises to better adapt to the international environment, better conduct OFDI behaviors, and improve the success rate and efficiency of OFDI.

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Bibliometric and Systemic Analysis of Production Planning Optimization

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Abstract. Having good production planning is essential to companies who need to maximize the use of their resources and boost their profits. However, to formulate efficient production planning is necessary to consider many variables. That makes analytical solutions almost impossible, forcing companies to use computational methods to solve this kind of problem. Even so, because of the complexity of the problems, much computational effort is needed. In that sense, using 4.0 industry concepts, like artificial intelligence, has been helping companies formulate optimal, or near-optimal, production plans for their process in a feasible time. Since each company has different characteristics and variables, the possibilities to formulate and optimize production planning are diverse. Thus, many case studies can be carried out. Generating a huge range of research opportunities. So, this study is a survey attempting to find some of these gaps through a systemic and bibliometric analysis. To achieve this goal the methodological procedure Knowledge Development Process – Constructivist (ProKnow – C) was used. This method aims to minimize the amount of content out of alignment with the research subject. In the first search, 44,609 articles were found, and after a filtering process that prioritized scientific recognized articles and journals, only 15 articles remained. Finally, common themes among the articles and opportunities for future work were highlighted.

Keywords. Artificial intelligence, optimization, production planning

Introduction

Production Planning is one of the most important strategic decisions that a company can make [1]. It is a fundamental element in cost control at companies. And it determines the quantity and the sequence that products will be produced to accomplish the request in a time horizon [2]. Because of the complexity of this kind of problem, a lot of computational effort is required. In that sense, using 4.0 industry concepts, like artificial intelligence, has been helping companies formulate optimal, or near optimal, production plans for their process in a feasible time [3].

The concept of 4.0 Industry emerged in Germany on 2011. And it became in 2013 an official initiative to revolutionize the German manufacturing system [4]. This concept proposes build a production system super flexible of personalized products and services, with real-time interactions between people, products and the production process [5].

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Industry 4.0 can be divided in five main parts: digitalization; production optimization and customization; adaptation and automation; human machine interaction; value-added services and businesses; and automatic data exchange and communication [6].

Since each company has different characteristics and variables, the possibilities to formulate and optimize production planning are diverse. Thus, many case studies can be carried out. Generating a huge range of research opportunities. So, a bibliometric and systemic analysis about Production Planning and Optimization in Industry environment was made seeking to carry out a generalized analysis on the topic and aiming to find common themes among the articles and opportunities for future work.

This article is divided in five sections. In the section 1 is presented the research methodology. In section 2 is presented the process to filter the bibliometric portfolio. In the section 3, the bibliometric review is made. In the section 4, the systemic analysis is presented. Then, in section 5, it contains the conclusion.

1. Methodological Aspects

The first thing that researches do to develop a work and build knowledge in some context is a bibliometric review about the subject. Frequently researches have difficulties to find the desired information and lost their time with not essential readings [7]. In that sense, the method ProKnow-C, Knowledge Development Process - Constructivist was used.

The ProKnow-C was developed by the Multicriteria Decision Analysis Laboratory (LabMCDA) of the Federal University of Santa Catarina (UFSC). It is a methodology that pursuit knowledge development structured in four stages. The first stage is the selection of the bibliographic portfolio, the second is the bibliometric analysis of the portfolio, the third is the systemic analysis of the portfolio and the fourth stage is the elaboration of the research opportunities [7].

This method helps to develop the knowledge of the research subject by selecting the most relevant articles. In that sense, is verified the main authors about the theme, the main keywords and the scientific prestige. ProKow-C has been applied in many fields, e.g., public administration and ambient disclosure [7].

2. Bibliographic portfolio selection

The first step to start searching articles is defining the search axis. In this work, three axes were defined. The first is Production Planning, the second is Optimization and the third is Manufacturing. The chosen keywords for the first axis were Production Planning and Rolling Horizon; for the second axis were Optimization, Optimal Production and Nesting; and for the third axis were Manufacturing, Supply Chain, Industrial and Metal Industry. To create the search key was necessary to use the Boolean operators “AND” and “OR”. So, the search key was ("PRODUCTION PLANNING" OR "ROLLING HORIZON") AND ("OPTIMIZATION" OR "OPTIMAL PRODUCTION" OR "NESTING") AND ("SUPPLY CHAIN" OR "INDUSTRIAL" OR "MANUFACTURING" OR "METAL INDUSTRY").

The next step was to choose the databases to search the articles. In this step, were chosen some of the relevant databases available in the periodical portal of the Coordination of Improvement of Higher Education Personnel (Capes), based on correlated areas and the possibility of advanced search. The selected databases were ScienceDirect (Elsevier), Scopus (Elsevier), ProQuest, SAGE Journals, Springer Link, Web of Science and EBSCOhost.

After the selection of the databases, the key search was applied in each database and 44,609 articles were found. In that sense, the use of some filter was necessary to reduce the size of the portfolio. The Figure 1 presents a synthesis of the filtering process.

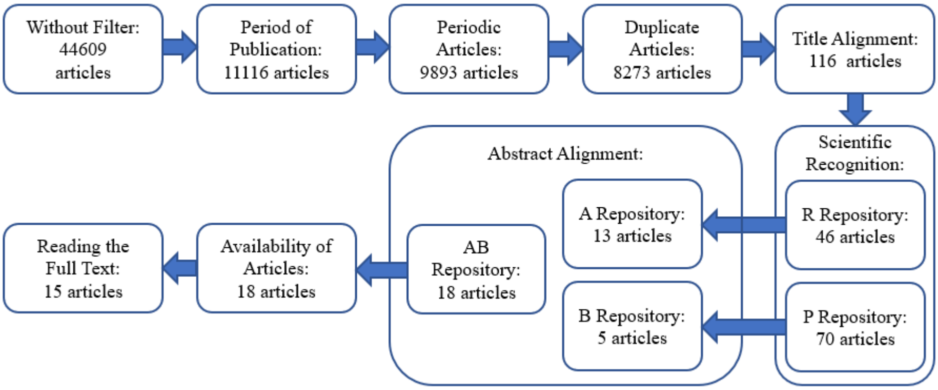

Figure 1. Synthesis of the filtering process.

2.1. Period of Publication

Only articles from the last 5 years (2015-2020) were considered, so articles published before 2015 were discarded. In that way, the number of selected articles drop to 11,116, representing 24.92% of the initial portfolio. This step aims to choose the most recent articles, avoiding topics that are not relevant at the moment.

2.2. Periodic Articles

Only periodic articles were considered. The number of selected articles drop to 9,893, representing 22.18% of the initial portfolio.

2.3. Duplicate Articles

The portfolio was polluted with repeated articles. These spare articles were deleted, and the portfolio size drops to 8,273, representing 18.55% of the initial value.

2.4. Title Aligment

In this stage articles that the title did not match with the subject were discarded. Only 116 articles remain in the portfolio representing 0.26% of the initial portfolio.

2.5. Scientific Recognition

In this stage the portfolio was divided in two groups. The R Repository represents the group of articles that already have proven scientific recognition. And the P Repository represents the articles that do not have relevant scientific recognition. To do this division was necessary collect the number of times that each article was quoted. The articles were ordered from the most quoted to the least quoted. In that way, the most quoted articles that together had 80% of the total citations were selected to compose the R Repository, totalizing 46 articles. The remaining articles were placed in P Repository, totalizing 70 articles.

2.6. Abstract Aligment

At this stage the abstract of all articles from R Repository was read. And the articles that had the abstract aligned with the research subject were placed in the A Repository, totalizing 13 articles. For the P Repository were read the abstracts of the articles published from 2018 onwards or the ones that were written for at least one author belonging to the A Repository. The articles that had their abstracts aligned with the research subject were placed in B Repository, totalizing 5 articles. So was created the AB Repository containing the articles from A Repository and B Repository, totalizing 18 articles and represents 0.04% of the initial portfolio.

2.7. Availability of Articles

All articles from AB Repository had their full text available for access.

2.8. Reading the full text

All articles from AB Repository were fully read and 15 articles were selected to compose the bibliographic portfolio of this research, representing 0.03% of the initial portfolio.

3. Bibliometric analysis of bibliographic portfolio

In the bibliometric analysis stage is performed a statistical analysis of the 15 articles belonging to the research portfolio. This step is important because it helps to confirm the scientific relevance of the choosen papers. The first analysis is the journal's relevance. To perform this analysis was compared the number of articles that were published in each article. In that sense, the most relevant journal was Computers and Industrial Engineering, that comprise 20% of the portfolio. This comparison can be seen in Figure 2.

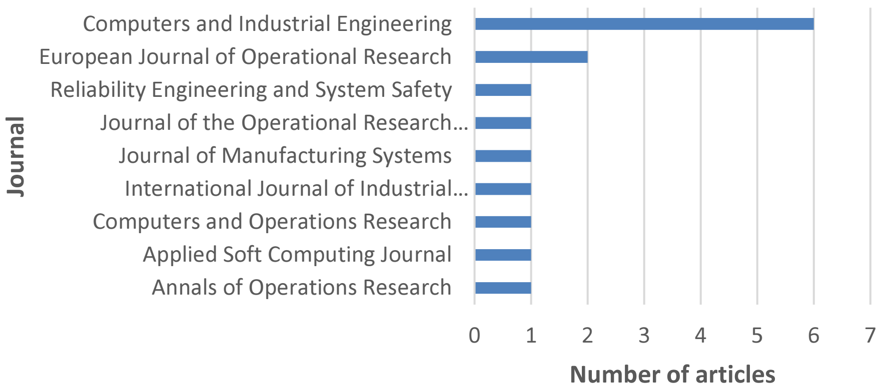

Figure 2. Estimation of journal's relevance.

The Table 1 was developed in order to analyze the scientific recognition of the portfolio. The most quoted article was *A possibilistic environment-based particle swarm optimization for aggregate production planning*, it was quoted 30 times, representing 11.19% of the total number of citations. And least quoted article was *Aggregate production planning: A literature review and future research directions*, that was quoted 6 times, representing 2.24% of the total number of citations.

Table 1. Number of citations.

Article	Citations
A possibilistic environment-based particle swarm optimization for aggregate production planning	30
Production scheduling and nesting in additive manufacturing	28
Optimal production planning for assembly systems with uncertain capacities and random demand	28
A multi-objective optimization approach for integrated production planning under interval uncertainties in the steel industry	26
Optimal production scheduling for hybrid manufacturing-remanufacturing systems with setups	24
Mathematical models and a heuristic method for the multiperiod one-dimensional cutting stock problem	20
An efficient genetic algorithm with a corner space algorithm for a cutting stock problem in the TFT-LCD industry	18
Integrated production planning and scheduling for a mixed batch job-shop based on alternant iterative genetic algorithm	18
Production planning of new and remanufacturing products in hybrid production systems	17
Production planning conflict resolution of complex product system in group manufacturing: A novel hybrid approach using ant colony optimization and Shapley value	16
A two-level method of production planning and scheduling for bi-objective reentrant hybrid flow shops	12

Article	**Citations**
Two efficient heuristics to solve the integrated load distribution and production planning problem	10
Multi-stage multi-product multi-period production planning with sequence-dependent setups in closed-loop supply chain	8
Hybrid simulated annealing and genetic approach for solving a multi-stage production planning with sequence-dependent setups in a closed-loop supply chain	7
Aggregate production planning: A literature review and future research directions	6

The 15 articles belonging the portfolio were written by 39 authors. 92.30% of the authors wrote only one article of the portfolio. *Somayeh Torkaman*, *S.M.T.Fatemi Ghomi* and *Behrooz Karimi* were the only authors that have more than one article written in the portfolio. They have written together 2 articles, representing 12.33% of the portfolio.

Among the 15 articles of the portfolio, 63 keywords were identified. Only 9.52% of the keywords were used in more than one article. The most relevant keyword was *Production Planning* being used 8 times. Followed by *Closed-loop supply chain*, *Flow shop*, *Genetic algorithm*, *Reverse logistics* and *Rolling Horizon* being used 2 times each.

In order to analyse the impact factor of the journals the 2018 edition of the Journal Citation Report (JCR) was used. The *International Journal of Industrial Engineering Computations* was not considered because it does not have a JCR. The journal with the highest JCR was the *Applied Soft Computing Journal* with impact factor of 4.873. In Figure 3 presents a graphic showing each journal with their respective JCR.

The last analysis is about the year of the publications of the 15 articles of the portfolio. 2015 was the year whit the highest number of publications. Five articles were published in that year, representing 33.33% of the portfolio. In the Figure 4 is possible to observe the total number of articles of the portfolio published in each year.

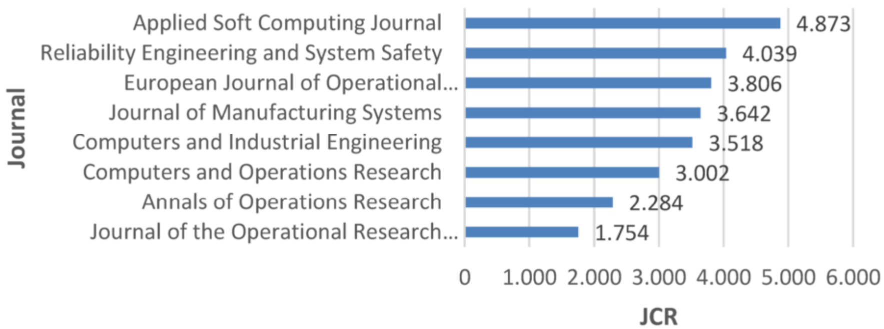

Figure 3. JCR Analysis.

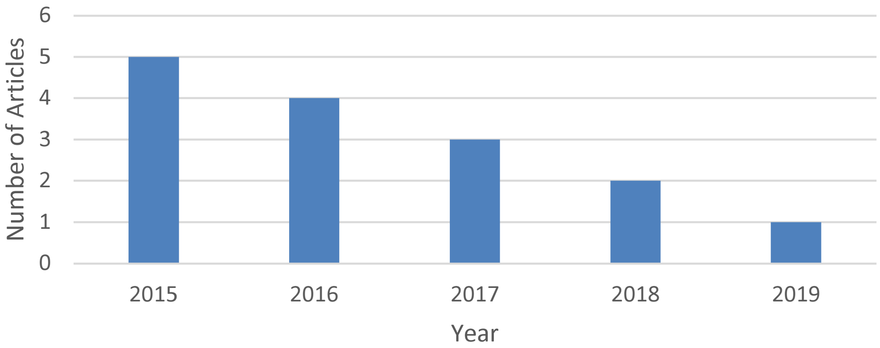

Figure 4. Number of published articles per year.

4. Systemic analisys and review discussion

The systemic analysis is important because it seeks to build the knowledge around a broader picture of the research subject. After reading the 15 articles of the portfolio, a content analysis was made. The analysis concerned to find main research problems, the means of solving these problems, trends and future research opportunities.

Production planning problems can be mixed whit many other problems, e.g., nesting in additive manufacture [8], assembly systems with uncertain capacities and random demand [9], complex product systems [3], hybrid flow shops [2], load distribution [10], uncertainties in industry [11], and integrated with scheduling [12]. Those varieties of applications make production planning a subject with many opportunities for future research.

Torkaman, Fatemi Ghomi and Karimi, 2017 [13] e Torkaman, Fatemi Ghomi and Karimi, 2018 [14] try to solve a production planning problem in a closed-loop supply chain. The problem is formulated using mixed integer programming (MIP). In order to solve the model, MIP-based heuristics using rolling horizon were developed. In [13] a simulated annealing algorithm was used to solve the problem. In [14] a hybrid algorithm using simulated annealing algorithm and genetic algorithm was used. For future work is suggested considering the uncertainties related to remanufacturing such as the amount and quality of returned products and reprocessing time, and, solve the problem as a multi-objective problem.

Another problem that has a huge impact in production planning is reverse logistic. Fang, Lai and Huang, 2017 [15] and Polotski, Kenne and Gharbi, 2015 [16] have faced the challenge of coordinate a production system that have new and remanufactured products. These systems are known as hybrid systems. In [16] the focus of research was address the optimal scheduling for hybrid manufacturing–remanufacturing systems with setups. In contrast, in [15] was considered capacity limitation, the durability of the recycled used product, competition between the new and used products, and the maximized total profit. As a future work is proposed incorporating the inventory of the remanufactured product to investigate the impact on the profitability.

Developing a technique which aggregates all the production information is a difficult task. These problem in called Aggregated Production Planning (APP). Chakrabortty et al., 2015 [17] proposed an approach that minimizes the risk to obtain the higher total cost and maximizes the possibilities to obtain the lower total cost. To solve the problem in [17] was used particle swarm optimization and genetic algorithm. Cheraghalikhani, Khoshalhan and Mokhtari, 2019 [18] made a review about this subject and for future work was proposed study stochastic and multiple objective models for APP.

According to Poldi and Araujo, 2016 [19] multiperiod cutting stock problem arises in the production planning of many industries. Lu and Huang, 2015 [20] investigated a two-dimensional cutting stock problem in the thin film transistor liquid crystal display industry. Mixed integer programing was used to build the problem. Because of its complexity was necessary use genetic algorithm to find a solution. In [19] was presented a mathematical model to solve a cutting stock problem in which demand occurs along a planning horizon. For future research was proposed to extend the solution to two-dimensional cutting stock problems, the inclusion of capacity constraints and integrate lot sizing with cutting stock problem.

Research opportunities were identified through the systemic analysis of the articles. Some of them are shown below:

- Optimize a production planning considering uncertenties on the process and random failures.
- Optimize a production planning considering muti-objectives and using hybrid metaheristcs.
- Optimize a production planning of a cutting stock problem considering a larger range of variables, e.g., transport costs, setup costs and delivery time.
- Optimize a production planning of a hybrid system considering remanufacture products inventory and government regulations.

5. Conclusion

Production planning directly affects the efficiency of a company, and because of its complexity, require a lot computational effort. In that sense, 4.0 industry concepts, through artificial intelligence technics, have been helping formulate optimized production plans. A bibliometric and systemic analysis was made seeking to build knowledge about the subject and find research opportunities. The methodology used to conduct this work was ProKnow-C, because it helps to find articles more aligned with the research subject. At the beginning, a lot of articles related with the search key were found. In that sense, the use of some filters was necessary. So, in the end of the bibliographic portfolio selection, only 15 articles were chosen. A bibliometric analysis of the portfolio was made, aiming to discover the scientific relevance of the articles. And finally, a systemic analysis was made to investigate the content of the articles, highlight common themes and find gaps for future work.

Acknowledgement

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Delivery Demand Peak Leveling Based on Customer's Acceptance Capability Analysis

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Abstract. As large scale E-commerace platforms rise, the delivery demand peaks are becoming more remarkable. This is mainly caused by sale promotions and one-day delivery promises. In this field, there is an implicit assumption that re-allocating the deliveries to level delivery peak results in lowering customer utility and thus, the mainstream approach is to make efficient the work plan in given conditions. This paper analyzes real delivery data, and indicates the possibility of delivery re-allocation without lowering customer utility, if an transdisciplinary approach of customer analysis and vehicle routing is applied. A delivery allocation system based on this implication was proposed, and a simulation based case study was conducted. Through this, the effect on delivery demand peak leveling without lowering customer utility, was verified.

Keywords. Delivery peak leveling, Customer acceptance capability analysis, Realtime delivery capacity analysis, Customer-Logistics capability matching

1. Introduction

As large scale E-commerce (EC) platforms rise [1], the delivery demand peaks are becoming more remarkable. This peak is mainly caused by sales promotions and one-day delivery promises. These peaks result in low occupancy rate of deilivery assets and work enviornment detoriation of delivery workers. Due to its large impact on delivery cost and quality, this is one of the major issues for logistic companies.

The main approach taken now, is to take this demand peak as a precondition, and to make the work plan efficient using both strict algorythms and heuristic algorythms [2]. An alternate approach exists of analyzing and smoothing the demand peak through delivery allocaton [3][4][5], but this usually results in lowering customer utility and thus, is not considered much practically.

However, there is a limitation to the existing optimization approach and an alternative approach is needed. Through real data analysis, this paper aims to show the possibility of delivery re-allocation without lowering customer utiliy if an interdiciplinarty approach of customer analysis and logistics analysis is taken.

In Section 2 and Section 3, the possible effectiveness of this approach is shown through analysis of delivery result data of a Japanese logistics company. In Section 4, a delivery allocation system is proposed based on this implicaton. The systems's peak shifting effect is evaluated in Section 5, following with a conclustion in Section 6.

2. Customer acceptance capability analysis

When considering delivery re-allocation, customers tend to be considered as one large persona. An example of this is shown in Figure 1. Although this gives a broad understanding ande model of customer acceptance capability, important information when considering precise delivery allocation is lost in the aggregation process. In this analysis, delivery result data from 2018/9/23 to 2020/4/31 of a Japanese to-Consumer EC and logistics company is used.

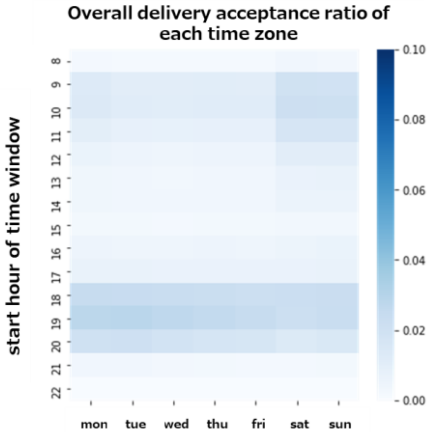

Figure 1. Overall average customer calculated from delivery data.

One information lost is the time zone in which each customer are capable of receiving their deliveries. Figure 2 shows a clustering result of customers using features acceptance hour ratio (8:00~14:00/14:00~18:00/18:00~23:00), and acceptance day of week ratio (weekdays/weekends). Cusomers with more than 20 orders within the data period was used. This shows that although largest cluster is close to the overall average, there are many smaller yet sufficient clusters where customers accept packages at a different time zone.

Figure 2. Clustering result of customer acceptance time zone.

Another information lost is the area size of acceptance of each customer. There are customers who only accept deliveries at a narrow time zones and others who accept them at a wider one. Figure 3 shows the distribution of the area size of acceptance, defined by the number of cells needed to cover 50% of the customer's acceptance performance. It is shown that the area size varies per customer.

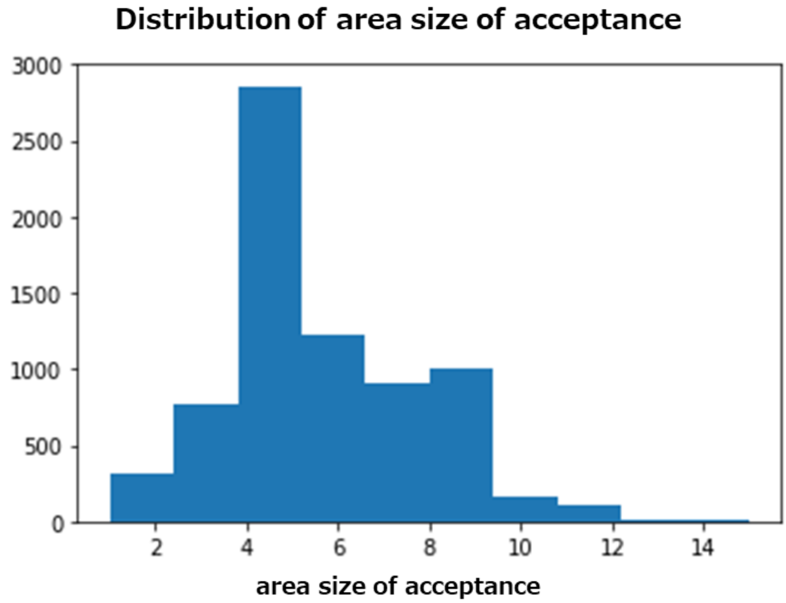

Figure 3. Distribution of area size of accpetance.

From the analysis above, it is shown that the delivery acceptance capability of each customer vaies sufficiently, and that this variance could be used to allocate deliveries to certain customers.

3. Delivery capability analysis

To accomplish a viable delivery allocation, in addition to the customer acceptance capability point of view, the delivery side point of view is also needed. Without this, an excess amout of deliveries could be allocated to a certain time zone.

At the present, there is a heuristic static capability limit set for each delivery zone or truck driver at each time zone in order to avoid this overflow. However, this results in a very conservative limit and tends to lower the occupancy rate and also lowers customer utility through delivery refusal at certain time zones

In contrast with the current static capacity approach, a real time delivery capability analysis is proposed. This concept is shown in Figure 4. In this approach, following the conditions shown in Equation 1, an approximate efficient delivery route is consecutively calculated. The conditins in equation 1 assure that order restrictions of time windows are met. Through this approach, the geographical characteristcs of each customer could be taken into account and thus, a finer delivery capacity analysis could be achieved.

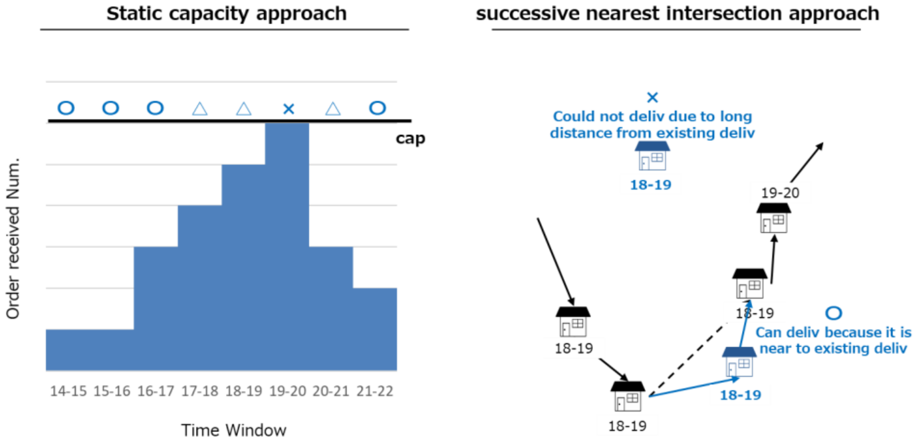

Figure 4. Concept of proposed real time delivery capability analysis.

$$min$$

$$Index_{i,j} = timeDelta_{i,newCustomer} + timeDelta_{newCustomer,j} - timeDelta_{i,j}$$

$$s.t$$

$$timeWindow_f(a) \leq timeWindow_s(b) \Leftrightarrow a < b$$

$$timeWindow_f(b) \leq timeWindow_s(a) \Leftrightarrow b < a$$

…(1)

$timeWindow_s(\mathrm{x})$: time window start of customer x

$timeWindow_f(\mathrm{x})$: time window end of cusomer x

Through simulation, it was shown that this approach could correctly expands the limits of delivery accpetance capacity. Delivery data of a delivery area with fine data was selected and used in this simulation. There is an one-to-one correspondence in delivery are and driver in this data. From the distribution of number of customers visited in a delivery shown in Figure 5, it could be seen that the ordinary capacity is around 15~20 customers throughout the delivery. The outliers happen when there is no other option but to exceed the limits heuristically set, and this results in sudden overwork of drivers. Figure 6 shows the distribution of the number of customers which could be visited in simulation within various order scenarios. The orders are generated according to an aggregated probability of the real delivery data, and delivery parameters such as delivery time off truck are set with margin. Thus, this number is both realistic and viable.

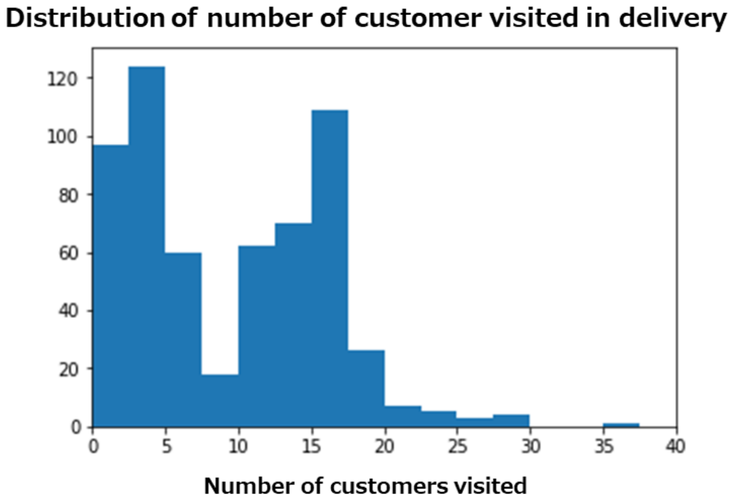

Figure 5. Current distribution of customers visted in delivery.

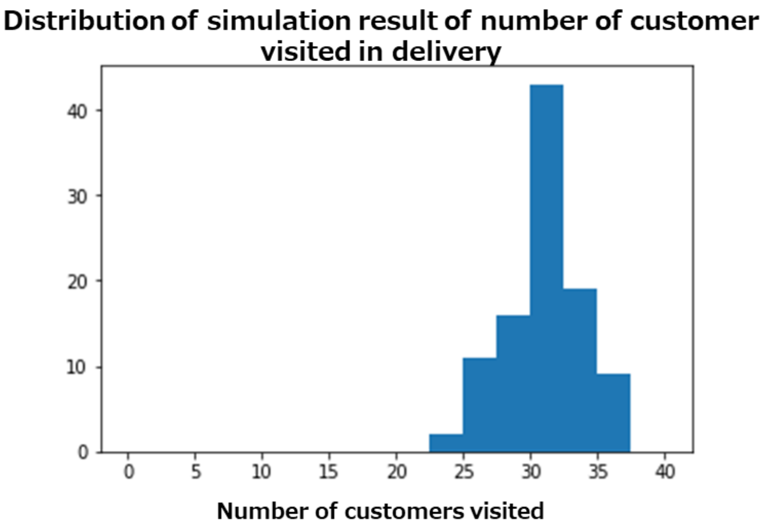

Figure 6. Distribution of number of customers which could be achieved.

From the analysis above, it is shown that delivery capacity could be finer derived through the successive nearest intersection method. This could correctly expand the logistics side capabitliy, and make re-allocation of deliveries more effective.

4. Proposed System

Based on the implications of customer acceptance capability analysis in Section 2 and delivery capability analysis in Section 3, a delivery allocation system shown in

Figure 7 was proposed. In this system, customer acceptance capability is estimated from past delivery results, and realtime develiry capacity for each customer is estimated from the order status. The two estimations are then matched, to derive the delivery timezone.

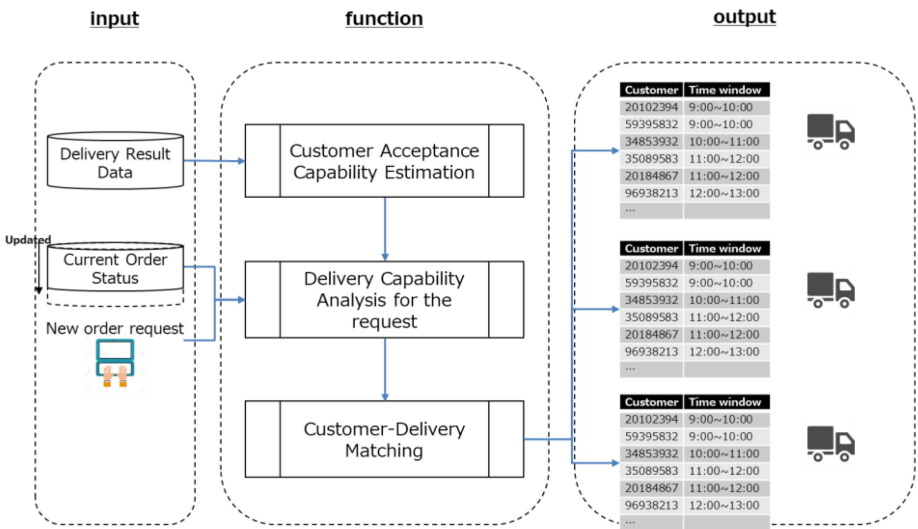

Figure 7. Proposed overall delivery allocation system.

4.1. Customer acceptance capability estimation

The delivery results for each cusomer are aggregated to derive the customer acceptance capability. The customers with insufficient ammount of data would be applied with an ordianry one-day delivery.

4.2. Delivery capacity estimation

A mix of the confidential static capacity approach, and the successive nearest intersection approach shown in Section 3 is used. The confidential approach is first taken to measure the remaining delivery capacity of each time zone. After this is exceeded, the succsssive nearest intersection approach is applied, and if the customer is judged deliverable, the remaining delivery capacity would be set as 1 for the specific customer.

4.3. Customer-Delivery matching

After the customer acceptance capability matrix and delivery capacity matrix is calculated by Sections 4.1 and 4.2, the hour and weekday which minimizes equation 2 is selected as the delivery date and time. This concept is shown in Figure 7. The two matrixes are both normalized so that the sum of numbers add up to one when put into this function. β and γ are parameters set to express the priority of customer and delivery

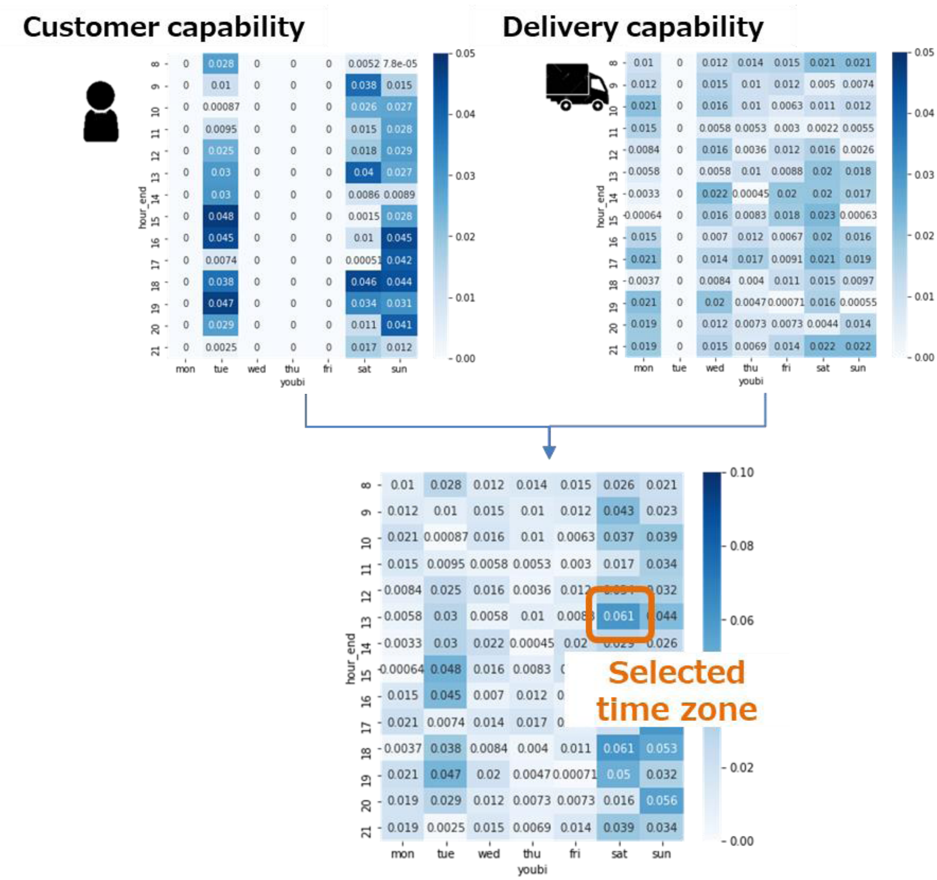

Figure 7. Customer - Delivery matching concept.

$$matchIndex_{hour,day} = \beta * customerCap_{hour,day} + \gamma * delivCap_{hour,day} \quad \ldots(2)$$

5. Case study

Through a case study based on the delivery data mentioned in Section 2, the peak shift effect was validated. The delivery area mentioned in Section 3 was used for the same reasons.

In this case study, a scenario where an excess ammount of orders are given from customers in one single day. The status quo is set as trying to deliver all the orders by one-day delivery. As stated in Section 3 the area is usually delivered by a single driver, but in these occurances, a second, third driver is committed using high cost.

The result of peak shifting is shown in Figure 8. It is shown that when applying the proposed system to a realistic scenario, the peak delivery demand peak is effectively leveled.

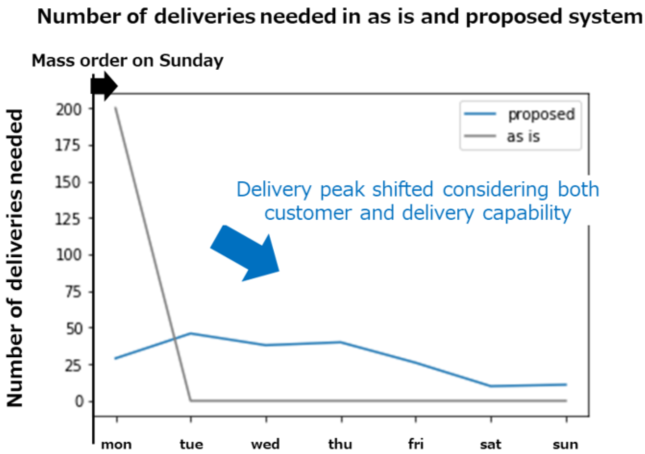

Figure 8. Number of deliveries needed in as-is and proposed system.

6. Conclusion

In this paper, an alternative transdisciplinary approach for demand peak leveling was investigated and proposed. From the customer acceptance capability analysis and delivery capablitliy analysis, the possiblity of delivery re-allocation without lowering or even uplifting customer utility, was shown. Based on this implication, a realtime delivery allocation system was propose, and throught a case study, its effect was evaluated and verified.

Future works could be

1. constructing an algorythm to estimate customer acceptance capabitliy for customers with small or no data
2. making the devliery capacity analysis finer by analyzing and modeling each destination's off-truck time
3. inserting an delivery re-allocation incentive process in the system to make the allocation judgement more decentralized

By combining conventional optimization approaches and the proposed delivery allocation approach, a social-optimal supply chain could be constructed.

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A Revamp of the Internal Quality Auditing Process

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Abstract. In this paper, the researchers have described the development program used for the internal quality auditors of Company A. This program was developed to increase the competency of the auditors so that they could effectively conduct both internal and external audits. The competency of the auditors was an important requirement according to the various management standards like the ISO 14001:2015, ISO9001:2015, IATF 16949:2016, ISO45001:2018 and IECQ QC 0800000. Furthermore, this program exposed all the auditors to the internal audits according to the requirements of the ISO 9001 standards and the in-process quality audits, which were divided into 6 areas for 8 months. For ensuring the success of the program, 15% of the auditors' Key Responsibility Areas (KRA) were attributed to their performance and their contribution to the general internal auditing program. The different Subject Matter Experts (SME) trained the auditors based on the requirements of the managing standards and their auditing skills. A monitoring technique was established for assessing the competency level of the auditors. The auditors, who showed a good performance in these programs, were recommended to partake in the Lead Assessors program and were asked to audit local or internal-external suppliers.

Keywords. Competent auditors; Internal quality audit; Effective auditing: Monitoring method

1. Introduction

Internal audit falls on clause 9.2 of various management standards such ISO 9001, ISO 14001, ISO 45001 and ISO 27001, to name a few. The extent of internal audit programme is based on size , nature and complexity of a business. According to ISO 9001 standard [1], a quality audit included a 3-step process, i.e., determination of the auditability of all planned processes with regards to the objectives of the study; conformity of the activities with the objectives; and the efficiency of the activities in

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fulfilling the objectives [2]. The internal audit must be effectively conducted for determining the operational performance of the organisation [3]. Implementation of an audit programme needs to be monitored, measured and reviewed. Mustika [4] proposed the research model based on the factors which affected the effectiveness of the internal audit process, as shown in Figure 1.

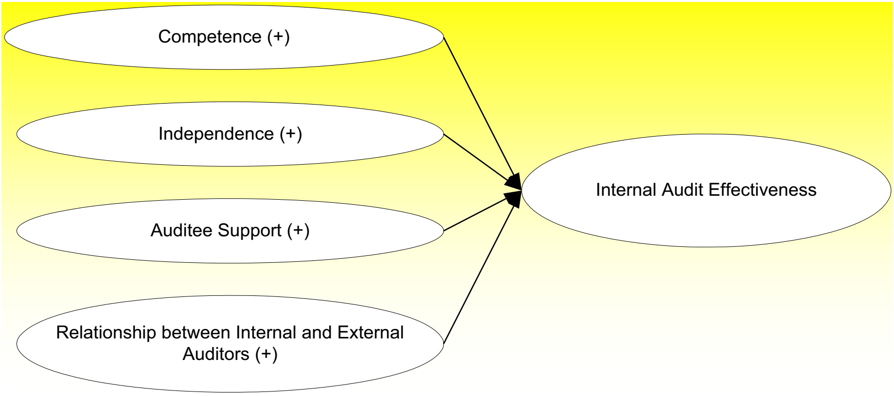


Figure 1. Factors affecting the effectiveness of the internal audit process [4]

To have a successful internal audit programme, an organization needs to have competent auditors. To ensure competency, this pool of auditors is to be evaluated regularly. The researchers studied the developmental program for internal auditors in Company A which was ISO9001 certified. In this manufacturing sector, internal auditors did not solely carry out full-time audits. Hence, performing internal audit was not a priority to the auditors. A revamp on the internal auditing program was established to have competent auditors. This was set as one of company objectives. In order to achieve this, an auditor competency program was set up.

2. Literature Review

The internal audit programs determine if the organisations were 'fit for their stated purposes'[2]. An earlier study Asiedu and Deffor [5] mentioned that effective internal audit sessions could detect corruption. On the other hand, Naheem [6] stated that an effective internal audit process detected money laundering processes. Kabuye et al. [7] noted that internal audits detected fraud management.

The internal audits review and monitor the operations carried out by an organisation and could suggest some steps for its improvement [8]. The use of novel technologies, processes and policies could help the organisations to ensure that the objectives of the company were fulfilled [9]. The factors which could affect the efficiency of the internal audit process included the competency, objectivity and independence of the auditors, audit reporting and planning [3,10-11]. Roussy and Brivot [12] stated that an effective internal audit process required better management support. Tackie et al. [13] observed that these factors did not affect the effectiveness of the internal audit process in the organisation. Similar results were also noted earlier [13-14].

Based on the earlier results Sari and Susanto [15] it was concluded that the competency of the auditors significantly affected the audit quality and the supply chain for the information systems. Work experience was required for detecting the presence of any irregularities in the system. Results noted by Shamki and Alhajri [14] showed that it could significantly affect the auditors' performance with regards to the areas they were familiar with. Furthermore, Christ et al.[16] presented a rotational program set up for the auditors which acted as a training base for improving their work experience. Competent internal auditors carried out an effective auditing process. Some of the other characteristics of effective auditors were - skilful when talking to people, the ability to establish relationships; asking questions in an intelligent manner [17]. Lee and Park [18] stated that a larger number of internal auditors in the organisation contributed to more effective audits.

Rogala [19] observed that some of the auditors failed because of unsatisfactory training levels, lesser time for preparing audits (which required combining the activities of an internal auditor and other primary activities), and finally, a lack of recognition by the organisation's management for the auditor. Nwannebuike et al. mentioned that it was better to train the internal auditors instead of developing some error-proof internal auditing processes [20]. The recruitment process used for internal auditors must be clear and transparent. The organisation's management must always motivate internal auditors and cooperate with them during the auditing process. They also need to be trained regularly for improving their auditing skills. Similar results were noted earlier by [11].

3. Proposed framework

The auditing scope was initiated based on the ISO9001 standard. Evaluation criteria for competency of auditors was set up by a group of Subject Matter Expert (SME).

Round 1 of the internal audit programme was done in 8 months for 6 different areas. One of the evaluation criteria for internal auditors was applying knowledge in specific disciplines in in-process areas. The in-process audits were categorised into six categories which were SERI (Special Engineering Request Instruction), TEI (Temporary Engineering Instruction), Qualification & Recipe (Tool Qualification & Recipe), SPC (Statistical Process Control), QRB (Qualification Review Board) and Corrective and Preventive Action System (CAPA).

The researchers selected 19 auditors from the technician and engineering levels. This pool of auditors are from different areas such as outgoing quality, in-process, quality management system, in-coming, statistical process control technicians and engineers. Auditors were initially internally trained based on the ISO9001 standard, in-process categories above and "generic" auditing processes and theories. Auditing process requires detailed planning skills. Audit dates, audit checklist and previous audit report follow up need to be prepared ahead. During audit, listening and asking questions techniques are needed to ensure audit objectives are met. After the audit, report writing skills and follow ups on action items or findings raised have to be completed to close the whole audit process.

Based on the internal audit areas scheduled, the auditor developed and submitted checklist to the SMEs for further reviewing. The SMEs reviewed this checklist and returned it for further editing or correction if needed. The SMEs then observed the complete auditing process and noted the auditing skills and performance of the auditors. After auditing process was completed, SME would review observations and comments to the auditor for future improvements. Auditor then submit audit report to SME for review before report was sent to the auditee for approval.

The SMEs would list the details regarding the audit that must be conducted. For each auditing subject, the SMEs listed the scope and the criticality factors necessary for preparing the checklists and the items which have to be verified, as described in Table 1.

Table 1. Audit area, scope and various criticality factors.

Audit Area	**Audit Scope**	**Audit Criticality**
Statistical Process Control (SPC)	• SPC violation reduction • Cpk improvement	• Critical parameters /repeated violators captured in weekly and monthly SPC violation report.
Corrective & Preventive Action (CAPA)	• CAPA disposition Defect event	• Defect event title with highest hit (detail analysis to determine more effective approach) • Shortcut during disposition
Temporary Engineering Instruction (TEI)/Special Engineering Instruction (SERI)	• Audit category based on TEI/SERI Type • In-progress TEI/SERI • Expired TEI	• Evaluation run for Inline Yield Issue • Evaluation run for Process Issue • Evaluation run for Process Optimization/Improvement • Evaluation run for Qualification Optimization
Qualification (Tool Qualification)/Recipe	• After PM and process qualification • High Runner and Non RMS tool • QRB recipe change	• Qualification (Tool Qualification) Audit • Tool qualification • After PM (Preventive Maintenance) Tool qualification • Recipe Audit;
Qualification Review Board (QRB)	Event related to :- • Recipe Optimization • Tool qualification • Direct/ Control material qualification	• Yield improvement project • Insufficient data's QRB event

3.1 SMEs' Audit Score Guideline

Table 2 presents the guidelines used by the SMEs to grade the auditors with regards to every auditing procedure. 10 points were allocated for every category. A maximal of 40 points could be attained for every audit.

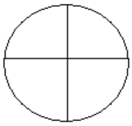
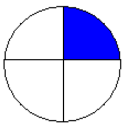
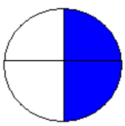
Table 2. Audit score guidelines.

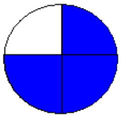
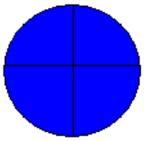
Areas	Points	Guidelines
Level of Difficulty	5 to 7	Audit - verification of Compliance
	8 to 10	Audit - verification of Effectiveness
Quality of Report	8 to 10	Acceptable without amendments
	5 to 7	Requires minor modifications with <2 times resubmission
	1 to 4	Requires major modifications with >2 times resubmission, direct supervision required
Audit Preparations & Promptness	8 to 10	Well prepared and on submitted ahead/onetime without much assistance required
	5 to 7	Prepared and submitted on time with certain level of assistance required.
	1 to 4	Not fully prepared, delay in report submission and heavy involvement of supports required.
Audit Process	8 to 10	Covered planned audited area within time, able to grasp overall system to access effectiveness
	5 to 7	Focus on compliance evidences
	1 to 4	Need SME intervention

3.2 Progression of the Auditors' Skill Level

The scores of the auditors were categorised based on their skill levels in Table 3. The SMEs were on default at Level 5 based on their auditing skill level. The progress of the auditor's process was tracked each month for determining if their skill improved.

Table 3. Skill levels of the Auditors.

Level	List Of Requirements of Each Skill Level
1 	1. Audit material know-how: a. Understand basic audit requirements b. Understand what a requirement is (either from ISO standard or specific procedures) c. Understand to put requirements into audit questionnaires 2. Audit skills: a. Adequate skill to ask question b. Adequate skill to look for compliance evidence c. Basis skill of audit report updates d. Audit capabilities limited to IQA, verification compliance to requirements e. Audit capabilities limited to specific compliance audit, or simple element of ISO standard requirements 3. Supervision required: a. lose supervisor from mentor and requires input updates to ensure audit performed and audit report done correctly. b. Necessary coaching needed during actual audit, in terms of putting proper verbal question to ask, and looking for evidences.
2 	1. Audit material know-how: • Adequate understanding audit requirements • Adequate understanding of linking specific requirements to ISO requirements to specific procedures • Able to structure audit checklist requirements 2. Audit skills: • Able to audit looking with equal skills to look for effectiveness of the system. • Able to write the audit reports correctly per audit report guidelines • Audit exposure for internal ISO audit • Audit capabilities limited on internal audit activities 3. Supervision required: • Certain level of supervision required to ensure checklist is adequate, coaching during audit and modification required on audit report
3 	1. Audit material know-how: • Capable cover both Level 1 and Level 2 2. Audit skills: • Capable to make judgement when to review for effectiveness of the system • Able to make logistical arrangement of the audit with certain supervision required • Audit capabilities cover up to external audit (local audits) 3. Supervision required: • Minimum supervision required to facilitate smoothness of the auditor's audit preparation • Certain level of supervision required to perform external local audits

4 	1. Audit material know-how: • Capable cover all Level 1, Level 2, Level 3 2. Audit skill: • Capable cover all Level 1, Level 2, Level 3 • Capable to cover external audit (oversea) • Able to show the capabilities to work independently 3. Supervision required: • Limited supervision required
5 	1. Exceed Level 4 with additional capabilities: • Understand to look on known ISO element in the bigger scope and link to the requirements in particulars for external audits • Able to look for effectiveness of the system and using known ISO elements as basis reference points • Able to provide coaching to other auditors 2. Able to be a SME to audit activities

3.3 Weightage for the KRA(Key Reseponsibility Area)

Before initiating the audit revamp program, the structure of the program was presented to the top management for their approval. It was agreed that 15% KRA was allocated to every auditor for their annual performance appraisal. Every auditor was assigned a minimal number of audits which they had to complete every year. For SME, the management established that 20% of the KRA was to be allocated for the project. The additional allocation was set aside for every SME as they had to ensure that the objectives of the process were fulfilled by the year-end. Audit results, reports and the non-conformance reports were to be further monitored so that they could be improved. The auditor levels were identified and reported. The auditors who scored >30 points were recommended to undergo the lead assessor program. Thereafter, they were allowed to conduct external auditing process (which supported the incoming quality group with regards to the suppliers auditing) in the international and local organisations.

3.4 Rotation Schedule

Each auditor was required to conduct audit on the in-process areas specified on rotation basis monthly. Figure 2 highlights the rotation schedule for the auditors. The detailed audit item to be conducted will be prepared by the relevant SME and communicated to the auditors at the first week of the month.

4. Results & Discussion

Figure 3 describes the performance of the auditors in Round 1 of the auditing process. The maximal number of audits which an auditor can conduct is 14, while the minimum number was 5.

	March	April	May	June	July	August
Rotation Schedule						
Auditor A	TEI	SERI	QRB	CAPA	Qual	SPC
Auditor B	SPC	TEI	SERI	QRB	CAPA	Qual
Auditor C	Qual	SPC	TEI	SERI	QRB	CAPA
Auditor D	CAPA	Qual	SPC	TEI	SERI	QRB
Auditor E	QRB	CAPA	Qual	SPC	TEI	SERI
Auditor F	SERI	QRB	CAPA	Qual	SPC	TEI
Auditor G	TEI	SERI	QRB	CAPA	Qual	SPC
Auditor H	SPC	TEI	SERI	QRB	CAPA	Qual
Auditor I	Qual	SPC	TEI	SERI	QRB	CAPA
Auditor J	CAPA	Qual	SPC	TEI	SERI	QRB
Auditor K	QRB	CAPA	Qual	SPC	TEI	SERI
Auditor L	SERI	QRB	CAPA	Qual	SPC	TEI
Auditor M	TEI	SERI	QRB	CAPA	Qual	SPC
Auditor N	SPC	TEI	SERI	QRB	CAPA	Qual
Auditor O	Qual	SPC	TEI	SERI	QRB	CAPA
Auditor P	CAPA	Qual	SPC	TEI	SERI	QRB
Auditor Q	QRB	CAPA	Qual	SPC	TEI	SERI
Auditor R	SERI	QRB	CAPA	Qual	SPC	TEI
Auditor S	TEI	SERI	QRB	CAPA	Qual	SPC

Figure 2. The Rotation schedule for the auditors.

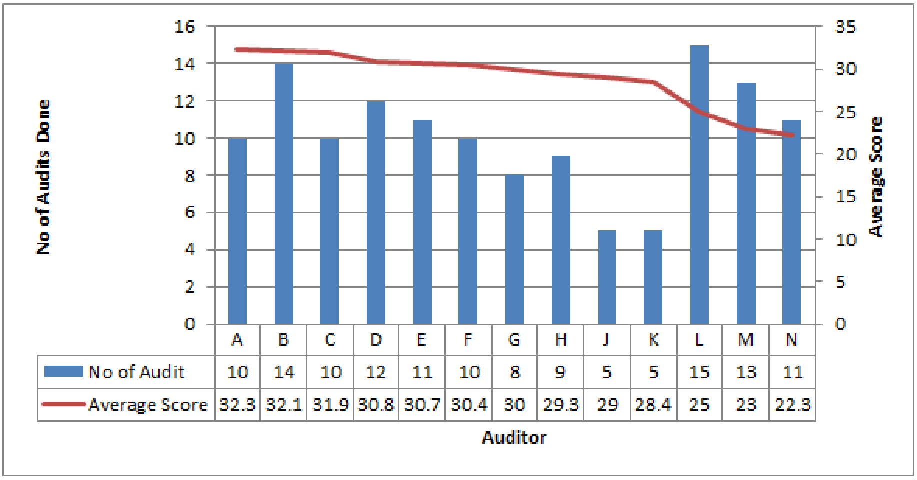


Figure 3. Performance of the auditors for Year 1 of the auditing process.

The auditors who conducted fewer audits were technicians who worked on shifts. It was observed that technicians received lower scores than the engineers. Table 4 presents an example of the data that was collected with regards to the auditor performance based on their areas. A few audits could not be completed since there were no samples or topics that could be audited, as determined by the SMEs.

Table 4. The performance of the auditors' based on the area to be audited each month (maximum score is 40 points).

	March	April	May	June	July	August
SPC	30.8	30.7	34	31.5	25.3	28.5
TEI	26.7	33	29	29.5		
CAPA	31.5	34	30	33	28.5	24
QRB	30.8	28.5	32.7		32	
Qual	31.8	27	32			
SERI		32.5	29	30.7	29	32.5

The status regarding the auditors' skill and training level after Year 3 of the program was described in Table 5. The number of auditors increased by >50%. After Year 3, 4 auditors were upgraded from Skill Level 1 to Skill Level 4.

Table 5. Status of the auditors' training status based on the standards.

Standard	**Lead Assessor: ISO9001**	**ISO9001**	**TS16949**	**IECQ QC 080000**	**ISO 14001**	**OHSAS 18001**
No of trained / certified auditors	5	28	11	26	17	24

Table 6 presents the number of audits which were conducted (external and internal) for 3 years. The auditing activities were seen to increase in Year 2 and decreased in Year 3 because of the business environment. In Year 2, the number of internal and external audits increased. The internal auditors with Skill 4 were selected for carrying out supplier audits, locally and internationally. This acted as a reward for auditors, who worked to upgrade their auditing skills.

Table 6. No. of audits carried out on an annual basis.

Year	**No of audits done - Internal**	**No of supplier audits done – Local**	**No of supplier audits done - Overseas**
Year 1	28	5	2
Year 2	53	10	4
Year 3	40	5	1

4.1 Moving forward

Due to business demands, organizations now carry more than one management standard such as ISO14001 (Environmental Management System), ISO 45001 (Occupational Health and Safety Management System) and ISO 27001 (Information Security Management System). The internal auditing program can be further improved to have competent auditors who can conduct multiple management system audits in one single visit. Furthermore, these management systems are now aligned to one common structure. It is easier to train auditors on interpreting and auditing them. Current move now is to train auditors to conduct integrated audits. Audit resources will be better managed with this.

5. Conclusions and Future works

Auditors need to have good auditing skills and management standard knowledge to achieve competency. These skills include understanding the audit objective, planning, writing, listening, asking questions and following up on the findings raised during the audit. The audit revamp program set up included training and monitoring programs for auditors (engineers and technicians) from different work backgrounds. Different in-process areas were audited on rotation basis. Subject Matter Experts who monitored the skill levels of the auditors and the standardised auditing score guidelines were part of the evaluation methods used. With practise, auditors will gain experience to perform better audits. Moving forward, organizations need to have versatile auditors who can conduct integrated audits to better manage resources. This will definitely be a bonus to the organisation.

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Sustainability

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Global Transport Challenges in Reducing Harmful Emissions: Selected Examples for Polish Part of Trans-European Road Network (TERN)

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Abstract. Environmental pollution is a significant problem for the whole world. The lack of response from states can lead to many consequences. As consumption increases, so does the emission of harmful substances. According to the European Parliament, almost 30% of total CO_2 (greenhouse gas affecting the greenhouse effect in the EU) comes from the transport sector, of which 72% is from road transport. Air pollution is a challenge for municipal authorities. According to the data, road transport accounted for approximately 5% of the creation of PM10 particles, ca. 7% of PM2.5 and approximately 32% for NO_X. In Poland, suspended particles (PM10 and PM2.5) cause deaths of as many as 45,000 people a year. Therefore, it is necessary to undertake concrete efforts in order to reduce vehicle exhaust emissions as much as possible. Among them, solutions such as downsizing, hybridization of combustion engines or electrification are used. Based on the analyzes, the authors of the paper drew attention to the significant impact, in this process, of the modernization of energy infrastructure. Thanks to this, it is possible to simultaneously increase the share of zero-emission vehicles as well as the use of VtG (Vehicle to Grid) technology. What's more, the authors of the paper have determined for the main communication routes (TERN) in Poland, the potential for setting up refuelling stations for new types of vehicles, such as hydrogen or electric cars. Finally, the main risks have been presented for drivers, infrastructure and environment as a result of proposed changes.

Keywords. transport, Trans-European road network, electric cars, hydrogen, hybrid

1. Introduction

Air pollution is a challenge for municipal authorities. Increased emission of PM10 and PM2.5 particles is particularly noticeable in Poland in the autumn and winter period.

According to KOBIZE (The National Centre for Emission Management) data [1], in 2016 the main sources of PM10, PM2.5, and PAH (Polycyclic Aromatic Hydrocarbons) emissions were non-industrial combustion processes (45%, 48% and 88% respectively of the total amount of emissions of such substances, estimated at

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259,156.3 Mg, 145,506.9 Mg and 146.3 Mg), the predominant share of which came from the combustion of solid fuels by households. In the case of nitric oxides (NO_X), the industrial sector was the biggest source of emissions (38% of the total amount of emissions of these substances, estimated at 726,431.2 Mg) but road transport was a second one (32%). Lack of enough airflow causes the above dust and others to stay suspended above the city, as a result creating smog [2].

According to these data, road transport accounted for approximately 5% of the creation of PM10 particles, ca. 7% of PM2.5 and approximately 32% for NO_X. In Poland, suspended particles (PM10 and PM2.5) cause deaths of as many as 45,000 people a year. The issue of smog also affects other European cities. Therefore, it is necessary to undertake concrete efforts in order to reduce vehicle exhaust emissions as much as possible [3].

Therefore, it is necessary to diversify the fuels used and vehicle propulsion methods. Introducing green solutions is key to sustainable development and improving air quality in cities and more. Therefore, along with the introduction of transport electrification, actions in the energy sector are necessary.

2. Energy Sector and green energy

The demand for electricity is growing in Poland. According to the available information, in 2017 more than 170 TWh of energy was produced in the country. It is 2.2% more than in 2016. Table 1 presents the division of electricity production from various sources for the years 2016 – 2018.

Table 1. Electricity production in Poland [4, 5]

Specification	2016	2017	2018
		GWh	
Total production	166 597	170 335	170 890
Thermal power stations	140 378	140 259	150 000
brown coal	51 082	52 281	49 400
coal	80 173	79 265	83 500
gas	5 604	6 161	12 200
biomass/biogas	3 519	2 552	4 900
Hydroelectric power stations	2 335	2 719	2 000
Wind power stations	2 981	3 485	4 800
Industrial power plants	9 897	11 417	12 200
Independent power plants – renewable energy installations	11 006	12 454	3 000

The analysis shows that, compared to 2017, electricity production from renewable energy sources (with the same installed capacity) dropped from 14.1 to 12.7 per cent. (21.6 TWh). Compared to 2017, in 2018 electric production from gas increased by 6039 GWh. Increases were also recorded in coal by 4235 GWh and biomass by 2348 GWh. In turn, declines were noted, among others in the production of electricity from brown coal - minus 2847 GWh; from wind farms - minus 2061 GWh; from hydroelectric power plants - minus 719 GWh. The production of renewable energy from solar farms is growing.

Data from the International Renewable Energy Agency (IRENA) indicate that for most of the decade Poland has grown several times faster than the rest of Europe and the world in terms of renewable energy. Thanks to this, from 2009 to 2018 our share in European RES increased from 0.59 per cent. in 2009 up to 1.61 per cent in 2016, to reduce to 1.53 per cent in the past year (2018) (in the case of the world, our share increased from 0.15 to 0.35 per cent during this time). At that time, progress was significant. Installed capacity increased three and a half times from 1.75 to 8.23 GW, while Europe has not even managed to double its green energy production potential (increase by 81.3 per cent).

According to the "National Plan for Energy and Climate for 2021-2030" developed by the Ministry of Energy, a forecast has been made of the share of renewable energy in the national energy mix by 2030. As part of the EU-wide 2030 target, Poland declares that it will achieve by 2030 21 % share of renewable energy in final gross energy consumption (total consumption in electricity, heating and cooling as well as for transport purposes), which depends on the competitiveness of these sources and their place and usefulness for the system.

In transport, a 10% share of renewable energy is expected to be achieved in 2020 and 14% by 2030. By 2030, an increase in the share of renewable energy sources is expected to reach about 27% in net electricity production. Pursuant to Directive 2009/28 / EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources, Poland was obliged to achieve a minimum share of 15% of energy from renewable sources in gross final energy consumption by 2020. You can so assume that despite the decrease in the share of renewable energy sources in Poland, it will increase by 2030 and the assumed goals will be achieved.

3. Charging stations for electric vehicles at the TERN transport routes – Proposal

Based on TERN transport routes and traffic forecasts on national roads in 2020, developed by GDDKiA, it was possible to determine road sections of the largest and most significant importance. These roads include, among others national road no. 7 (Tricity-Warsaw-Cracow), A1 motorway (Tricity-Lodz), A2 motorway (Warsaw-Frankfurt/Oder), A4 motorway (Swiecko-Cracow), express road S8-A1 motorway – national road 1 (Warsaw-Katowice) or national road 17 (Warsaw-Hrebenne).

On the above, it is proposed to deploy the fast-charging stations for electric vehicles. The distance between the charging points was calculated based on the average range of electric vehicles and the possibility of charging electric vehicles. The exact calculation of the distance between the charging stations is shown in Table 2.

Table 2. Calculating the distance between electric vehicle charging stations.

Condition	Range
The average range of electric vehicles when batteries are 100% charged	175 km
The average range of electric vehicles when batteries are 80% charged	140 km
Current reserve in 15% batteries	26 km
5% safety factor	~ 9 km
Distance between electric vehicle charging stations	~ 110 km

Based on the calculated distance between the charging points, it was possible to determine the minimum number of charging stations for electric vehicles on routes belonging to TERN.

The proposed application includes the construction of a quick charging station on the forecasted main transport routes in the country. Taking into consideration the assumptions regarding the distance between quick loading points and analyzing the possibility of their location, taking into account the current road infrastructure in the country (intersections, interchanges, road type), it was possible to determine the minimum number of charging points on individual routes. Calculating the distance between stations and the range of electric cars available on the European market has allowed the planning of the location of fast charging stations The following figure 1 presents a detailed proposal to build a quick charging station on specific road sections, being the forecasted main transport routes in Poland.

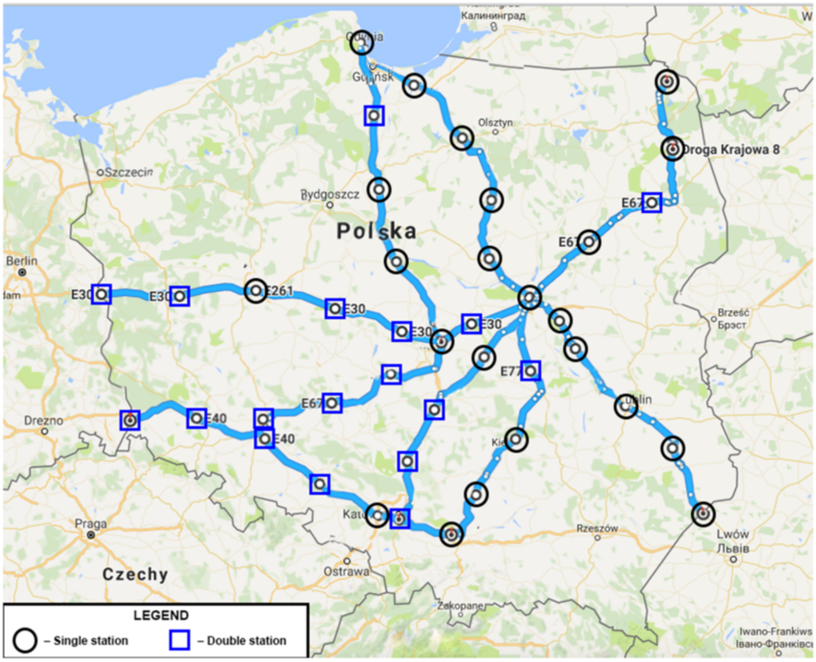

Figure 1. Proposal for fast charging station location.

Considering such variables as the location and infrastructure of given road sections, it was possible to determine the number of fast charging points for electric vehicles. Their minimum number should oscillate at around 60 points (the number of stations was determined on the basis of the average range of electric vehicles - it was calculated based on the range of electric vehicles available on the market and the rejection of those with the largest range). With this infrastructure, it will be possible to use electric vehicles on roads belonging to the TERN transport routes and constituting road sections that will be heavily loaded in the perspective of 2020, without worrying about the lack of places for charging vehicles.

Of course, the network of vehicle refuelling stations is much larger in the country. To optimize the costs of infrastructure construction, existing refuelling stations can be used during the construction of electric vehicle charging stations. This may prove to be a great help because of the 7807 petrol stations (as at the end of the third quarter of 2019). Similarly, given the analogy to cars with fossil fuels, whose range is usually over 500 km, the density of refuelling stations is much greater than 500 km, which results from a significantly larger number of cars powered by conventional fuel.4. The energy demand of an electric vehicle.

Based on own tests of an electric vehicle in real traffic conditions, it was possible to determine its average energy consumption. Then it was determined with the assumption of daily runs (about 60 km), what would be the energy demand for one vehicle and energy costs related to it. Table 3 presents the energy consumption needed to recharge the batteries of the vehicle.

Table 3. Annual energy consumption needed to recharge the batteries of one vehicle.

Specification	Parameter
Daily mileage on business days	60 km
Daily mileage on Sundays and holidays	60 km
Annual mileage on business days	15 060 km
Daily mileage on Sundays and holidays	6840 km
Total mileage	21 900 km
Price 1 kWh for a household (G11 tariff)	0,55 pln/kWh
The cost of charging one vehicle a year	2529,45 pln
Annual energy consumption needed to recharge the batteries of one vehicle	4599 kWh

Next, the results of the annual electricity consumption needed to charge the batteries of one electric vehicle were related to the assumed introduction in Poland of a million electric cars. On this basis, it was possible to determine the annual energy consumption needed to recharge the batteries of one million electric vehicles (Table 4). Then, the percentage of energy demand in the country will be estimated.

Energy consumption was calculated on the basis of own tests of electric vehicles in real road traffic conditions (RDE) with the use of the YOKOGAWA measuring device. After examining several electric vehicles available on the market, the test results were averaged and then used to calculate the average annual energy consumption of one vehicle and relate this to a million vehicles. The number of millions of vehicles is a reference number for Poland, which was specified by the government.

Table 4. Energy demand for powering electric vehicles.

Specification	Parameter
Annual energy consumption needed to recharge the batteries of one electric vehicle	4599 kWh
Annual energy consumption needed to recharge the batteries of a million electric vehicles	4,599 TWh
A change in energy demand while supplying a million electric vehicles	+ 2,7%

The calculations show that with one million vehicles the energy demand of the country will increase by 2.7%. This is not a significant change with regard to the energy demand in the country in 2017 and 2018, which amounted to over 170 TWh. However, in 2018 the import of electricity to Poland amounted to 5.7 TWh, which is why charging electric cars would increase it almost twice [6]. It is best for financial reasons that this process takes place at night. The tariff adopted for calculation is a tariff applicable to households (G11) and amounts to 0.55 pln/kWh. With this assumption, the annual costs related to the charging of an electric vehicle amount to 2529,45 pln. With regard to conventional vehicles, this is a significant difference at the moment.

5. Hydrogen and hydrogen stations

Area for practical use of hydrogen as a fuel carrier is transport, including in particular road transport. In recent years 2 motor companies (Hyundai, Toyota) have launched the serial production of fuel cell vehicles (FCEV) and others such as Volkswagen, Mercedes Benz, BMW, General Motors also produce such vehicles. The start of serial production by those companies depends on the availability of expanded hydrogen refuelling network of HRS (Hydrogen Refueling Stations). In 2016 there was the only c.a. 200 such stations available in the world. It is expected that by 2020 the number of HRS should come to approx. 1000 and by 2025 – to c.a. 3500 (Table 5).

Table 5. Number of public HRS worldwide in 2016 and their projected number in 2020–2025 [7].

Year	USA	Europe	Asia	Total
2016	60	100	103	263
2020	130	520	340	990
2025	600	2000	830	3430

This HRS in 2025 should provide service for approx. 2 million hydrogen vehicles. Currently approx. several thousand vehicles fuelled with hydrogen are used in the world, including more than 1000 in the US and 2000 in Japan and several hundred in Western Europe. Dynamic growth of fleets of hydrogen vehicles is planned – for example, China expects to have 50 thousand hydrogen vehicles in 2025, to eventually exceed one million in 2030, whereas Japan will have a fleet of 40 thousand hydrogen vehicles in 2020 and almost 300 thousand in 2030. According to projections of 2014 – the European fleet of hydrogen vehicles is expected to have 350 thousand vehicles in 2020, the fleet in Japan – 100 thousand, in Korea – 50 thousand and the US – 20 thousand [7].

Also, the fleet of hydrogen-fuelled buses is to be developed – in Europe it will have 1000 buses in 2020, while for instance in South Korea – almost 30 thousand buses by 2030.

In Poland, there are practically no vehicles equipped with fuel cells (for that reason, at present, it is impossible to obtain a vehicle of this type for energy consumption tests, such research will be conducted at a later date). However, it was developed by Motor Transport Institute "Circumstances of the national plan for hydrogenization of road transport in Poland". In the first place taken into account were [1, 8]:

– already existing refuelling opportunities in the neighbouring countries,

– the expected future HRS locations in the Baltic countries,

– gradually increasing the area available for hydrogen-powered cars as a result of the subsequent location of new stations at distances up to 300 km from the existing or sequentially from the newly opened ones [1].

With this criteria, the order of preliminary proposals to build base HRS in Poland are as shown on figure 2: 1 - Poznan 2 - Warsaw, 3 - Bialystok, 4 - Szczecin, 5 - Lodz area, 6 - Tri-City area, 7 - Wroclaw, 8 - Katowice region, 9 - Cracow [1, 8].

Figure 2. Map of Poland with marked sites of the proposed public hydrogen refuelling station locations [8].

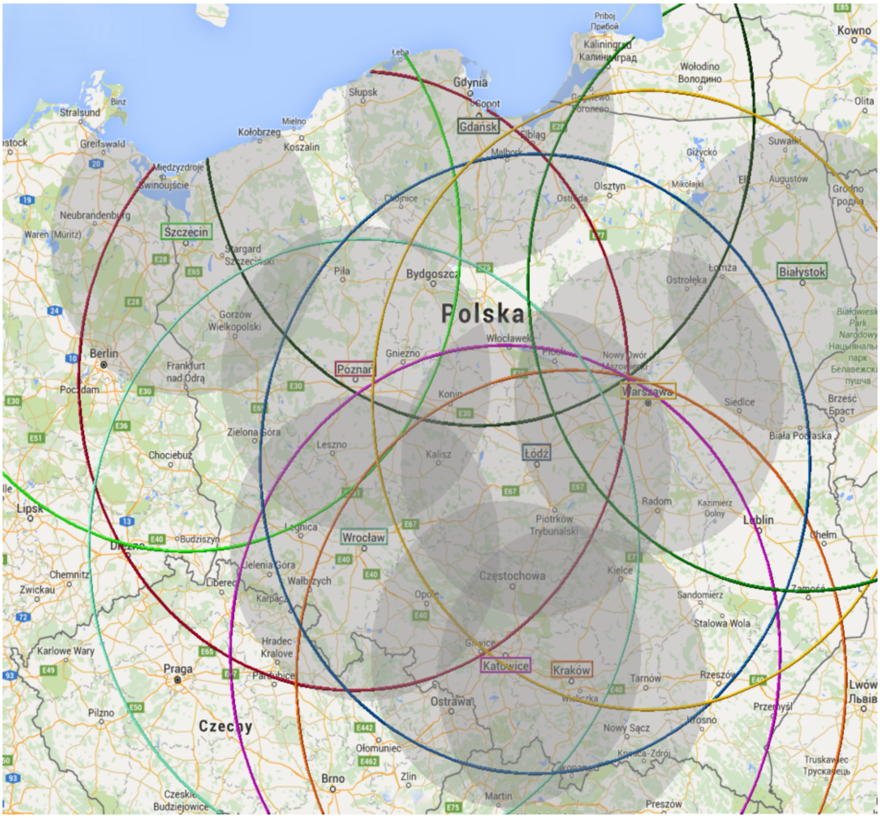

Figure 3. Penetration area of cars using fuel cells based on 9 hydrogen refuelling stations situated on the national TERN road network by 2030 [9] a) when driving in one direction (diameter of large circles – to approx. 600 km), b) when driving there and back (diameter of small, shaded circles - to approx. 300 km) [8].

Unfortunately, the estimates related to hydrogenation have not been met at the moment. The assumed plan to build 9-hydrogen refuelling points has not been implemented. It is assumed that in the coming years there is a high probability of establishing a station in Poznań and Warsaw.

6. PESTEL Analysis of charging stations for electric vehicles at the TERN

Political factors that can affect the development of fast-charging stations are very extensive. On the one hand, the EU wants Europe to be the first climate neutral-continent, on the other, Poland wants to delay this process for economic reasons. A change in Poland's policy to generate electricity and a move away from fossil fuels towards renewable energy sources will be of great importance. However, environments related to the mining industry may make systemic changes difficult.

The soaring costs of living and running a business are not conducive to investment in new technologies, and electric cars should be considered as such. Also, rising electricity prices mean that this type of transport is not developing well in Poland.

Social factors can support the process of transport electrification. The fashion of being an eco society, renting cars instead of buying, openness to new technologies, all this increases the interest in electric vehicles. In addition, the rapid development of technology strengthens interest, even by reducing production costs. However, only technical solutions that will shorten the charging time of an electric vehicle similar to the classic fuel method will attract new users. Such solutions are necessary to overcome the social resistance of people. Although legal factors can contribute to the development of fast-charging stations. Because the introduction of appropriate regulations and incentives will increase the sale of electric cars. In addition, inviters will be more interested in building new charging stations, especially since it is a simpler process than building a gas station. The lack of legal action will mean that nothing will change compared to the current state, and electric vehicles will be only curiosity and extravagance on Polish roads.

7. Conclusions

The development of the network of electric chargers and HRS in Poland along the roads belonging to TERN is a key aspect of the popularization of electric and hydrogen-powered cars. The most important aspects of system implementation are:

- Construction of nearly 60 fast-charging stations;
- The maximum distance between charging points is 110 km;
- Increasing electricity supply by nearly 3% per year;
- Construction of HRS in at least 9 major urban centres in Poland;
- Changes in the law supporting users of electric and hydrogen vehicles.

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A CAD Material Skeleton-Based Approach for Sustainable Design

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Abstract. In recent years, the development and application of sustainable product design have become a hot spot. With the development of computer technology as the core of the comprehensive technology, product management information system should integrate the sustainable material specifications early in process design. This paper proposes a conceptual model based on the concept of CAD skeleton where the material and function of the constituent elements are highly integrated to achieve sustainable products. A skeleton contains formally the following information: engineering requirements, performance requirements, materials and morphology. This information is defined by defined firstly by attachment, which relates to the immediate proximity of the importing and exporting of design loads; secondly by the functional structure which defines the simplified morphology to channel the loads and thirdly the envelope, which defines where the morphology of the part can be without interfering with others. Using the proposed formalism, the morphology of the product (geometry and topology) is formally driven by material requirements. Therefore, this approach allows the designer to design different product forms according to the material requirements of clients. An application shows the interest of the approach.

Keywords. Sustainable Design, Design for Material, CAD, Skeleton.

Introduction

The implementation of transdisciplinary engineering methods has brought materials engineers into the design process at an earlier stage. Materials and manufacturing are closely linked to determining the final product performance. New requirements have emerged for the materials of the sustainable product. The efficiency of the use of the material should be increased following the principle the just material is in the right place and just the necessary followed by the just material is in the right place [1].

The structure and the morphology of CAD product depend on many factors such as loading, materials, production methods, the structure of the product, joining and locating of parts, or appearance [2]. There is a necessity is to consider all these factors for establishing a sustainable design. It means that design should stably resist the changes [3]. Thus, modelling should reduce the random search process, minimize the iterative trial-and-error process [4] and endow the computer-aided design with creative power through the creation of the scientific methodologies [5]. Therefore, CAD modelling

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should be based on a theoretical foundation based on logical and rational thought processes.

Based on this assumption, a new approach that allows the product geometry and structure to be driven by the material specifications for sustainable design is proposed. This Design for the Material approach is implemented in a CAD system.

The remainder of this paper is structured as follows: In Section 1 the skeleton model is briefly introduced, followed by a formal model in Section 2. Section 3 describe an application of the formal model and Section 4 summarizes the conclusions and outlook.

1. Skeleton Model

A CAD skeleton holds the morphology of the future product [6]. The main objective of the skeleton is to validate in early phases of the CAD process the major specifications without spending time to define a detailed CAD model which will be reworked afterwards [7]. Skeleton is a basic concept in CAD modelling of machines and mechanisms [8][9]. Many researches have already been carried out using the skeleton based modelling [10-13].

Different types of skeletons and their roles in modelling are introduced in CAD modelling: part skeleton, assembly skeleton and motion skeleton [6]. Depending on the level of conceptualization, a skeleton is a simplified shape which is driven by functional requirements (FR) and embeds the design working principles [2].

A material skeleton solution represents thus the architecture of a product by defining the relationships between its simplified components to satisfy the material performances. Thus, the material selection will drive the morphology of the product.

The simplified model is enriched gradually to satisfy the whole set of *functional requirements* and *material requirements and constraints* imposed on the product.

A skeleton should formally contain the following information:

(a) Engineering requirements - design loads, performance requirements;
(b) Materials and
(c) Morphology.

On the other hand, the morphology is defined formally by:

- interfaces, which relates to the immediate proximity of the importing and exporting of design loads;
- architecture, which defines the simplified morphology to channel the loads;
- an envelope which defines where the morphology of the part can be without interfering with others.

2. A formal model for CAD Material Skeleton

Ideal modelling requires that the functions of the design are independent of each other. In the ideal case of total independence, the mapping FR to design parameters should show an uncoupled design. It means that each design parameter can be manipulated to meet a particular FR without affecting the other parameters or functions [2].

To generate in the first hand the material skeleton and in the second hand the morphology, we propose to split the FR into two types: (a) material requirements and (b) morphology requirements. This will allow the management of inputs for both, skeleton and morphology.

The selection of the proper materials for a design is a key step in the design process because it links early computing with the morphology of CAD models [14]. In computer-aided solid modelling, the designer defines the morphology and general dimensions of components. The product configuration thus depends on material selection. Equation 1 shows that architecture and the morphology of the product depend on material selection.

$$\begin{bmatrix} \text{Specify Material Requirements} \\ \text{Specify Architecture Requirements} \\ \text{Specify Morphology Requirements} \end{bmatrix} = \begin{bmatrix} a_{11} & & \\ a_{21} & a_{22} & \\ a_{31} & a_{32} & a_{33} \end{bmatrix} \begin{bmatrix} \text{Material Selection} \\ \text{CAD Architecture} \\ \text{CAD Morphology} \end{bmatrix} \quad (1)$$

It is the skeleton which defines the CAD architecture following the selection of the materials. The CAD morphology then depends on the skeleton.

The CAD architecture is defined by a CAD skeleton, which holds the morphology of the future product. The CAD morphology is defined by CAD part body design which supports and channel loads. However, the functional requirement "support and channel loads" depends on the material skeleton. Equation 2 shows this dependency.

$$\begin{bmatrix} \text{Hold the Body of the Product} \\ \text{Support and Channel Loads} \end{bmatrix} = \begin{bmatrix} b_{11} & \\ b_{21} & b_{22} \end{bmatrix} \begin{bmatrix} \text{Material Skeleton} \\ \text{CAD Part Body} \end{bmatrix} \quad (2)$$

Knowing that a material skeleton should import and export loads, channel the loads and no allow the interfering with other CAD parts, the managed dependency between these functional requirements is shown by equation 3.

$$\begin{bmatrix} \text{Import/Export Loads} \\ \text{Channel Loads} \\ \text{No Interfering} \end{bmatrix} = \begin{bmatrix} c_{11} & & \\ c_{21} & c_{22} & \\ c_{31} & c_{32} & c_{33} \end{bmatrix} \begin{bmatrix} \text{CAD Interface} \\ \text{CAD Architecture} \\ \text{CAD Envelope} \end{bmatrix} \quad (3)$$

Replacing equation 3 in equation 2 yields:

$$\begin{bmatrix} \text{Import/Export Loads} \\ \text{Channel Loads} \\ \text{No Interfering} \\ \text{Support and Channel Loads} \end{bmatrix} = \begin{bmatrix} b_{11} & & & \\ b_{21} & b_{22} & & \\ b_{31} & b_{32} & b_{33} & \\ b_{41} & b_{42} & b_{43} & b_{44} \end{bmatrix} \begin{bmatrix} \text{CAD Interface} \\ \text{CAD Architecture} \\ \text{CAD Envelope} \\ \text{CAD Part Body} \end{bmatrix} \quad (4)$$

Replacing equation 4 in equation 1 yields:

$$\begin{bmatrix} \text{Specify Material Requirements} \\ \text{Import/Export Loads} \\ \text{Channel Loads} \\ \text{No Interfering} \\ \text{Support and Channel Loads} \end{bmatrix} = \begin{bmatrix} a_{11} & & & & \\ a_{21} & a_{22} & & & \\ a_{31} & a_{32} & a_{33} & & \\ a_{41} & a_{42} & a_{43} & a_{44} & \\ a_{51} & a_{52} & a_{53} & a_{54} & a_{55} \end{bmatrix} \begin{bmatrix} \text{Material Selection} \\ \text{CAD Interface} \\ \text{CAD Architecture} \\ \text{CAD Envelope} \\ \text{CAD Part Body} \end{bmatrix} \quad (5)$$

The matrix $A[a_{ij}]$ in equation 5 shows an order relation in the management of CAD modelling. It shows that design modelling follows that principle: *material drives the morphology*.

3. Application

This section proposes an application of the material skeleton approach. The case of a Laval nozzle is presented. This study case is only a demonstrator of the approach viability. It will be now essential to implement this approach into an industrial case to validate the approach for the industry.

3.1. Material selection

Table 1 shows an Extract of the data repositories. In this example, the fuzzy geometrical interfaces are the geometrical entities located at the interfaces of the product, meaning the rocket engine where the nozzle is plugged. For the material specifications and rules, we can retrieve, based on previous experiences and the state of the art, a set of specifications and a set of rules.

Table 1. Table extract of the data repositories.

Repository Name	Categories	Value
Fuzzy geometrical interfaces	Engine interface	2 Plans 2 sections lines
Design requirements	Fluid mechanics shape	Internal spline with 6 control points Internal shape passing through 6 circles External spline with 6 control points External shape passing through 6 circles
	Pressure Temperature Velocity	From 0,1 to 8 Mpa From 1700 to 3300 K From 0 to 3 Mach
Material specifications	Graphite	To minimize ablation : Max pressure: 10 Mpa Max temperature: 3500 K Max velocity : > 3 Mach
	Graphite - Phenolic resin	To minimize ablation : Max pressure: 5 Mpa Max temperature: 2800 K Max velocity : > 3 Mach
	Silica - Phenolic resin	To minimize ablation : Max pressure : 1,2 Mpa Max temperature: 2000 K Max velocity : > 3 Mach
	4D braided Carbone / Carbone composite	To minimize ablation : Max pressure: 10 Mpa Max temperature: 3500 K Max velocity : : > 3 Mach

Repository Name	Categories	Value
Materials rules	Graphite	Thickness abaqus regarding mechanical constrains
	Graphite - Phenolic resin	Thickness abaqus regarding mechanical constrains
	Silica - Phenolic resin	Thickness abaqus regarding mechanical constrains
	4D braided Carbone / Carbone composite	Thickness abaqus regarding mechanical constrains

3.2. Material skeleton

From equations 3 the material skeleton is defined from CAD interface design, CAD architecture and CAD envelope. Figure 1 shows a section of the nozzle with fuzzy geometrical interfaces. The geometry satisfying the design requirements is represented by a fuzzy spline with 6 control points and the radius of the 6 circles forming the internal shape of the nozzle. The interaction with the engine is represented geometrically by two fuzzy segments (bottom left).

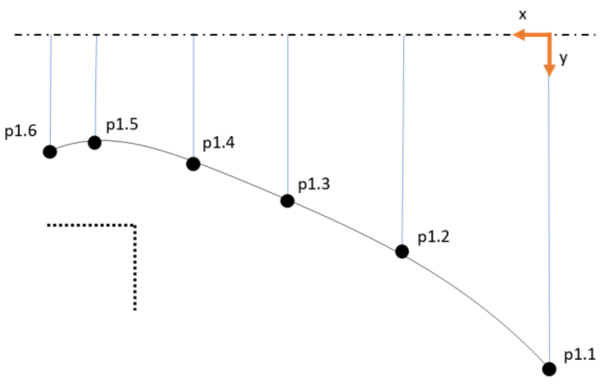

Figure 1. Section representation of nozzle with fuzzy geometrical interfaces.

3.3. CAD interface design

A CAD interface i is a geometrical entity laid on a layer i. For the nozzle, it is defined by a plan and two circles representing the internal and external diameter of the nozzle. Figure 2 shows the generated interfaces.

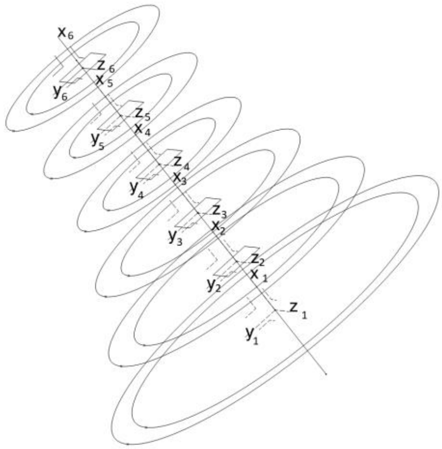

Figure 2. CAD interfaces.

3.4. CAD architecture

CAD architecture represents the geometrical relationship between CAD interfaces. Figure 3 represents the direct link between the interfaces. At each layer i , a coordinate system $R_i(O_i, x_i, y_i, z_i)$ is defined and associated with the interface i . A geometrical parameter x_{ij} defines the position of the centres of the interfaces i and j in their respective coordinate system $R_i(O_i, x_i, y_i, z_i)$ and $R_j(O_j, x_j, y_j, z_j)$ linked to these interfaces. Geometrical parameters are associated with the geometry of each interface. The geometrical parameters: the diameter d_i and the thickness e_i drive the geometry of the interface. The internal spline passing respectively through the 6 control points represent the computed aerodynamical shape of the nozzle. Finally, the interfaces with the engine, are represented by 2 plans and 2 segments lying on these plans.

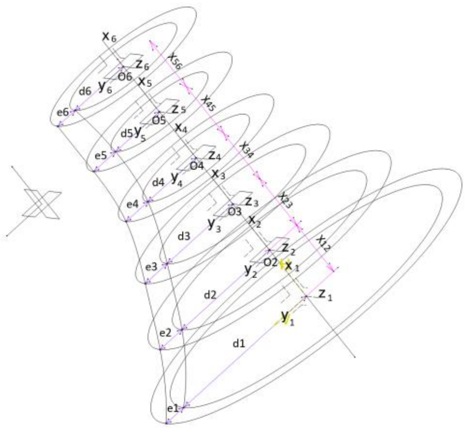

Figure 3. CAD architecture.

3.5. CAD envelope

CAD envelope defines where the morphology of the nozzle can be built without interfering with other parts of the system. Figure 4 represents the limit areas of the nozzle. The internal and external surfaces of the nozzle (coloured in blue) represent the envelope of the body of the nozzle; the contact surfaces of the engine, where the nozzle will be plugged, are also generated (coloured in purple).

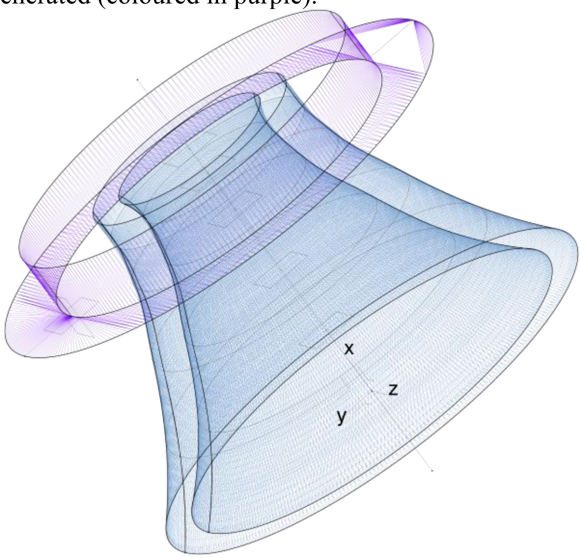

Figure 4. CAD envelope.

3.6. Generated material skeleton

The generic material Skeleton is composed of CAD interfaces, CAD architecture and CAD envelope (Figure 5). For each type of material, the designer can generate a specific skeleton containing the material information and a simplified morphology.

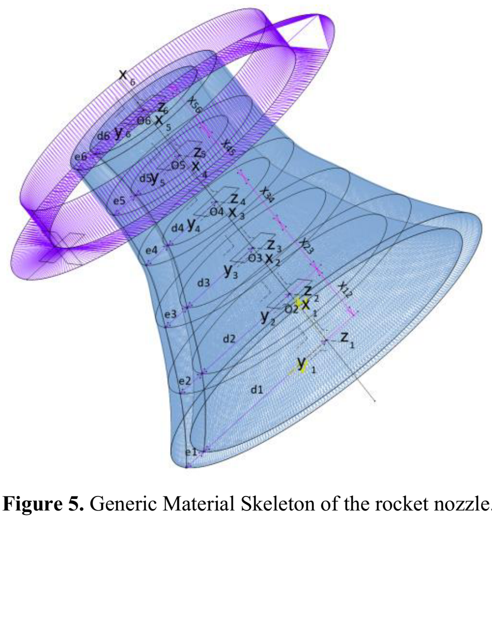

Figure 5. Generic Material Skeleton of the rocket nozzle.

The first option is the design with multiple materials following the principle: *the right material in the right place*. Three types of material: Graphite, Graphite - Phenolic resin, Silica - Phenolic resin are chosen for their properties (Table 1). The thickness e_i are updated. The multiple material skeleton is shown in Figure 6.

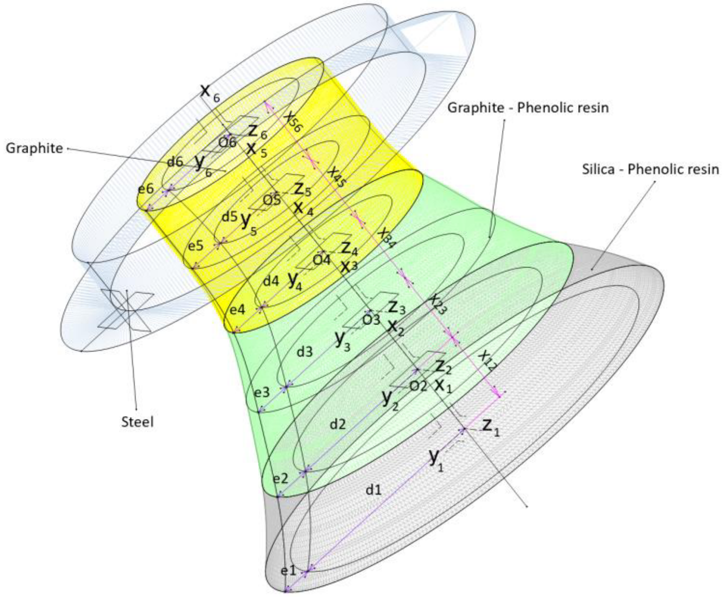

Figure 6. Multiple Material Skeleton of the rocket nozzle

The second option is the design of the nozzle with a mono-material: Carbone composite (Table 1). The mono-material Skeleton is shown in Figure 7.

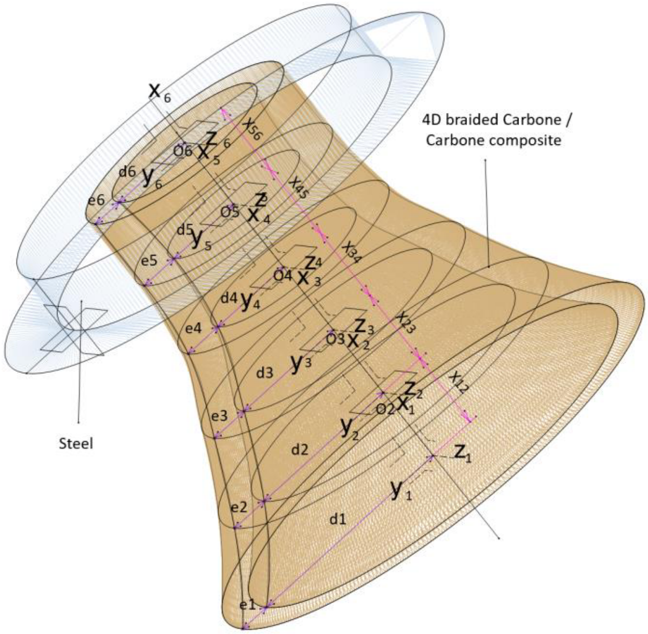

Figure 7. Mono Material Skeleton of the rocket nozzle.

3.7. CAD part body

After the generation of the material skeleton, the final morphology can be directly generated based on the specific skeleton. Figure 8 shows the CAD model based on the multi-material skeleton (Graphite, Graphite - Phenolic resin, Silica - Phenolic resin). Figure 9 shows the CAD model based on the mono-material skeleton (4D braided Carbone / Carbone composite).

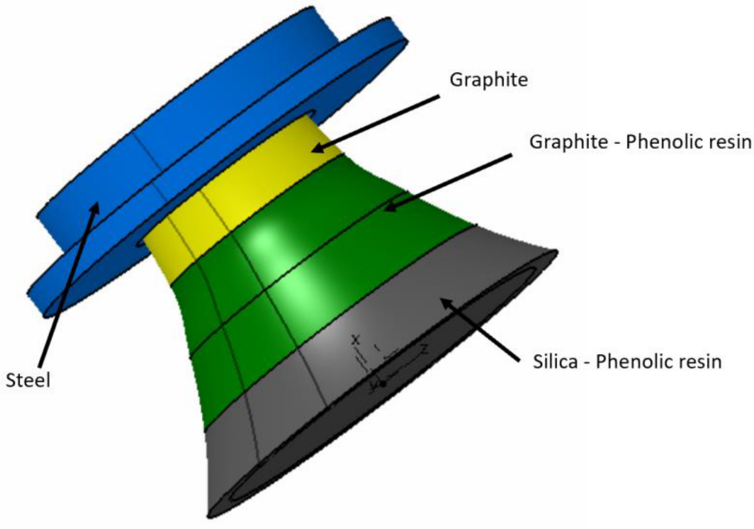

Figure 8. Product-based example on the material Skeleton for a multi-material.

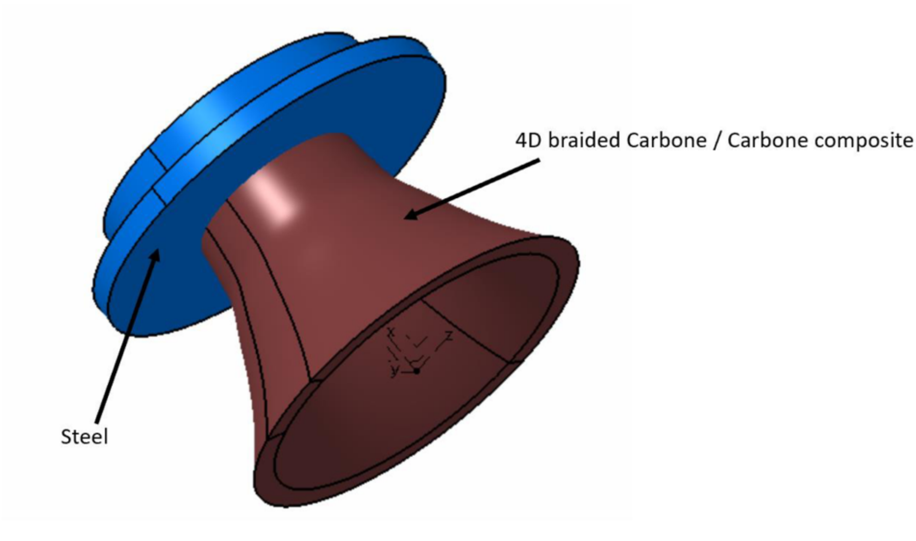

Figure 9. Product-based example on the material Skeleton for a 4D braided Carbone / Carbone composite.

4. Discussion and conclusion

Today, new requirements have emerged for a sustainable design using new materials. Therefore, the morphology of the product should emerge from a primarily material-driven design process.

Design for Material in CAD systems is an approach which satisfies the principle of the adaptive geometry driven by the sustainable material. Using the proposed formalism, the morphology of the product (geometry and topology) is formally driven by material requirements. Therefore, this approach allows the designer to design different product forms according to the material requirements of clients.

This approach structures also the definition of the material skeletons based on a cloud of points defined in an envelope [15]. This allows considering in the early phases of the design process the material specifications and distribution of engineering constraints.

Working with simplified models bring more flexibility in the design process [16]. The number of loops is reduced and the product emerges from the enrichment of a simplified model. Finally, this approach can be also adapted to different expert areas [17].

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