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Digital Master as an Enabler for Industry 4.0

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Abstract. Regardless of whether it is a question of business or private lives, education, economy, public management and services or politics – the digital revolution covers all areas of our daily life. For enterprises, this inevitable move means in particular: New technologies and changes in customer behavior and demands throw established business processes off track, opening entirely new possibilities and opportunities. Nowadays, digitization is often mentioned in the same breath with other buzzwords such as Mobile and Cloud Computing, Big Data, Business Intelligence, Internet of Things, Industry 4.0 or 3D Printing. However, this does not go far enough – there are more important drivers pushing the digitization and digital transformation for business organizations. Globalization is one of them, for instance, but also social changes with a new generation of customers – the Digital Natives. In this paper we illuminate the background of the digital transformation, and introduce the term Digital Master or 3D Master for the industrial purpose. We highlight the specific needs and expectations of the automotive industry. In a case study the application of Digital Master is shown in the production planning and quality assurance, based on a practical approach.

Keywords. Digital Transformation, Engineering Collaboration, Digital Master, 3D Master, Intelligent Document, 3D PDF

Introduction

The digital transformation is affecting almost every aspect of our daily lives in business and leisure. Humans gradually are getting surrounded with digital devices. Nearly everyone is constantly connected to new technologies and uses services accessible online. Chats, shopping, banking, travellling, apps controlling field services, storage or maintenance as a service are just a few [1]. For people in the working age it is getting challenging to embrace work and live with old technology. Employees very often are technically better equipped at home than at working place. Young customers are often more technophile than technology vendors, thus enforcing transformation. The important fact frequently overlooked is however that these services are available only recently and are intended to improve at fast rising pace. Both, companies and private consumers are affected by this transition in a similar way [2]. The market share of products and services which are not yet affected by digital transformation dramatically decreases.

As far as the enterprise is concerned, a major challenge consists of constantly adjusting products and services to changing conditions and continuously optimizing

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supply chains by means of modern technologies. Such measures improve flexibility and agility significantly. The market player, who is the fastest in offering compelling solutions for customers, will be able to increase its market attractiveness and competitiveness sharply, keeping costs per unit low. Digital transformation drives every modern organization to align processes more customer-centric, improve service, act even more agile or enter new markets and develop new products [3][4][5].

Potentials for competitive advantages arise from technological opportunities and innovations linked to digital transformation (such as human-to-human, human-to-machine and machine-to-machine interaction). The relationship between the business organizations and its customer can essentially surge by new possibilities of interaction [3]. Not only marketing or sales departments, that traditionally had always geared toward communication and interaction with customers will have to adapt to new technological opportunities, the typical internal divisions such as research and development, production and logistics as well will have to [6].

Digital transformation reinvents business models and their related internal processes as well as the way corporate entities interact with their customers and partners. In fact, the possibilities of digital media are changing businesses dramatically – strategies, processes, structures, products, services and cultures are affected. People, machinery and resources can communicate directly and in real time. Rigid value chains are increasingly transformed into dynamic value networks, where the added value is created in an interaction of constantly communicating and flexible successive reacting units, largely organized by themselves [4].

Digital transformation is useful in service business in particular. In the area of rehabilitational healthcare, it has provided great opportunities for developing smart healthcare product-service systems. Nevertheless, challenges still exist to achieve secure and effective tele-healthcare services, which are aligned for future improvements as follows: self-learning and self-improvement, use of wearable devices, standardization, privacy and security [7]. In context of service selection and composition, different providers may offer the same service with different attributes and the importance of such attributes is subjective and varies in different contexts. Dynamicity in real-time service workflow interoperation creates complexity, in which changes of services' attributes is constant occeurence, and needs appropriate selection process [8]. Similarly, in the area of product life-cycle energy management (PLEM) the solution provides additional information for decision-making, enabling better service selection in service workflow. This however is still at infant stage, when it comes to application [9][10].

Novel technological approaches are heighting the industrial adaptation process. They serve the interaction between those involved in the company and their respective customers, to further accelerate the communication and information exchange in order to provide individualized services in real time. Thus, reducing the reaction time of companies to changes and replacing standardized products by individual, customized products is getting more and more relevant [11].

The structure of the paper is arranged as follows: Section 1 briefly introduces the levers of the digital transformation. Section 2 is focused on the concepts and applications in the automotive industry. The concluding remarks are presented in Section 3.

1. Enablers of the digital transformation

There are different approaches to rule the digital transformation. In a management oriented approach, authors have identified six elements that define the changing digital agenda: context, culture, capability, connection, contribution and communication [12]. In contrast to this approach, we follow the technological and organizational transformation which can be aligned with the general approach [1] to be applied for the product creation process.

Digital maturity is a combination of two separate but related dimensions. The first, digital intensity, is investment in technology-enabled initiatives to change how the company operates – its customer engagements, internal operations, and even business models. Firms maturing in the second dimension, transformation management intensity, are creating the leadership capabilities necessary to drive digital transformation in the organization. Transformation intensity consists of the vision to shape a new future, governance and engagement to steer the course, and IT/business relationships to implement technology-based change [13].

1.1. Four levers of the digital transformation

Among the enablers of the digital transformation in the industry are the Internet of Things, a high-quality broadband coverage and an increasing automation of production. These aspects facilitate a new market positioning and value propositions, by means of Industry 4.0, fourth-party logistics (4PL) or Predictive Maintenance. Not only one of the single technologies and propositions aforementioned is paving the way for disruptive developments, instead a combination of them can be the solution. After all, the added value often derives from the interoperability of previously independent systems and the connection of previously separate spheres [1]. Network-centric operation occurs when systems are linked or networked by a common infrastructure, share information across geographic borders, and dynamically reallocate resources based on operational needs [14]. Digitization accelerates the evolutionary process in the field of products and services. The digital transformation influences the industrial change upon four levers:

Digital data: Based on an automated acquisition, processing, analysis and sharing of digitized mass data better predictions and decision making in shorter time will be possible, (which will be further presented in the section 2) [15].

Automation: Interoperability of traditional technologies with autonomous, artificial, smart, pervasive systems yields the reduced error rate, the shorter time-to-market and the drastically reduced operating costs in Industry 4.0 approach [16].

Networking: High-quality broadband telecommunication facilitates networking across the value chain, allowing to synchronize supply chains, to shorten production times and to improve innovation cycles.

Digital customer integration: The (mobile) internet allows to acquire direct access to customers and to offer them complete transparency and completely new services via new intermediaries, preserving their privacy [17].

The crucial value levers do not lie in technology but in the correct interpretation of the data arising along the value creation chain [18]. Who is able to establish strategic control points along data collection and data analysis will profit the most from the next industrial revolution. Disruptive changes in various enterprises yield to tremendous opportunities, growth and profit.

Hence, entire value chains are digitally disrupted, that is, innovative companies move from existing business models in adjacent areas. Various SMEs recognize the digital transformation as crucial for their business model and their business strategy. The secret of success is to understand the rules of the digital market and to set strategic checkpoints faster than competitors. Mere online players are often much better positioned than traditional companies. So they are able to take advantage of inefficiences in traditional supply chains and transform them to their benefit [13].

1.2. Impact on the automotive industry

Disruptive shifts are expected in the automotive industry and logistics [19][20]. Driven by shared mobility, connectivity services, and feature upgrades, new business models could expand automotive revenue pools by about 30 percent, adding up to $1.5 trillion. Despite a shift toward shared mobility, vehicle unit sales will continue to grow, but likely at a lower rate of about 2 percent per year. Consumer mobility behavior is changing, leading to up to one out of ten cars sold in 2030 potentially being a shared vehicle and the subsequent rise of a market for fit-for-purpose mobility solutions. City type will replace country or region as the most relevant segmentation dimension that determines mobility behavior and, thus, the speed and scope of the automotive revolution. Electrified vehicles are becoming viable and competitive; however, the speed of their adoption will vary strongly at the local level. Within a more complex and diversified mobility-industry landscape, incumbent players will be forced to compete simultaneously on multiple fronts and cooperate with competitors. New market entrants are expected to target initially only specific, economically attractive segments and activities along the value chain before potentially exploring further fields. Once technological and regulatory issues have been resolved, up to 15 percent of new cars sold in 2030 could be fully autonomous [21].

The original equipment manufacturers (OEM) and their major suppliers already started the transformation process in the automotive industry having a number of major programs initiated, inter alia, new stage of interconnectivity by introduction of the comprehensive IP protocol in the vehicle. It embraces full communication functionality and facilitates enhanced infotainment, better safety, highly automated and autonomous driving, and enhanced parking capability (Figure 1) [22].

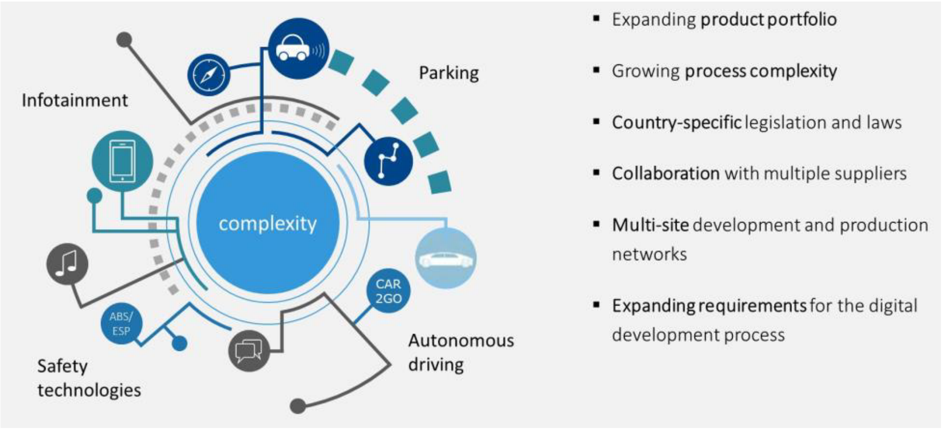

Figure 1. Digital Transformation at Daimler: Trends and Business Strategy [22].

New business models are seen in the expansion and complementation of the existing service portfolio, generating new potential for value creation and developing the business model from a product provider to a solution or service provider by adding a combination of intelligent services to the value chain [19][15]. Realizing this is empeded with massive hurdels: The services intended to be offered are already accessible from the driver's mobile devices.

Simplexity – which is a complementary relationship between complexity and simplicity – is going to become dominant and most powerful driver for optimization. For example, by reducing the number of variants, a reduction of the effort is to be expected. An isolated view is therefore usually not possible. In addition, the potential of differentiation or standardization changes depending on the level of the considered product structure.

The following questions are crucial for the success of digital transformation in the field of automotive industry [1][19][20][22]:

- Who will exploit the gap of the digital communication interface between the vehicle and the drivers or vehicle operators?
- Who owns the rights of the data that is created in and around the car, who is allowed to conduct their further use and processing? Which data will be publicly accesible? Who is allowed to make an offering and distribute it to the driver and the passengers?
- How does highly automated driving change the individual mobility of the consumers and their behavior when buying a car?

2. Use Case Digital Master (3D model-based Master)

The fundamental vision of integration in manufacturing is to achieve continuous flow of information in all lifecycle stages. This vision affects three layers as illustrated in Figure 2.

As described in section 1.1 integration is a widely requested "digital data" lever for digital transformation. It describes a product (born digital) holistically with (1) domain-specific application models for example, mechanical or simulation models. It demands cohesive communication in the (2) supply chain based on CAx data streams with partner, in joint ventures and across factory plants. 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.

Product lifecycle phases are affected differently by computerization. Physical products that were primarily mechanical are becoming more digitized. Systems Engineering has evolved to the prevailing development approach in Engineering. In Manufacturing, novel trends are now embraced by Industry 4.0. Internet of Things finally offers great potential in service by e.g. linking physical products with corresponding digital twins.

2.1. Requirements of downstream processes

Usually only certain data is necessary at sequences (gates) for assessment in downstream processes. Large and comprehensive functionalities, such as provided with modern CAx systems are usually not mandatory. In fact, the number of consumers of CAD data in extended enterprise is about a factor of 10 at least higher than users in engineering, where product data is created. The use of powerful CAx systems in development processes is certainly justified. Their use however in downstream processes such as purchase, production, assembly and quality assurance needs to be scrutinized in the course of an efficient product creation. For such reasons an additional model called Digital Master (Figure 3) is introduced.

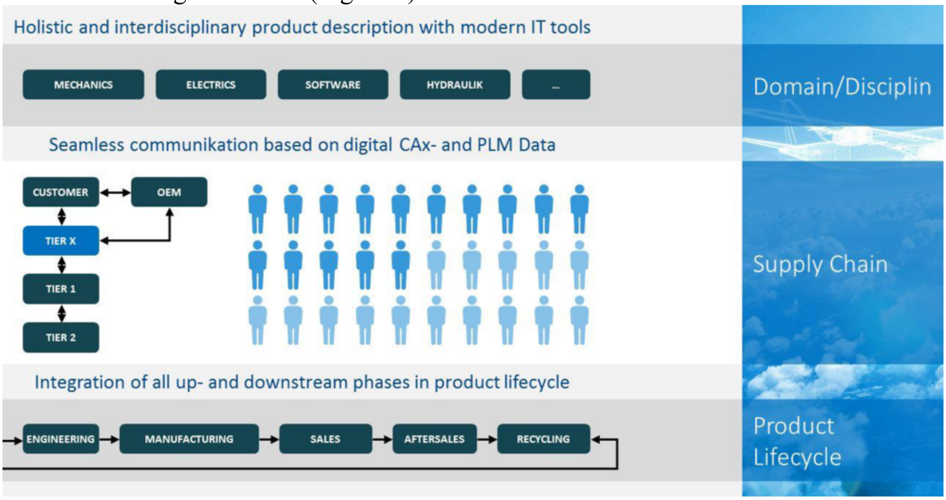

Figure 2. The integration vision in automotive industry.

The Digital Master enables the enterprise to collects, maintains and provides all system information at a dedicated point in time to all actors. Downstream process can access this information for their dedicated needs. Digital Master baselines allow traceability for all system elements.

Basically, the digital master represents a document-based approach in the development of complex products, which enables modern organization to share product data with downstream processes. Digital master models are a set of linked data records in self-contained document that provide a defined degree of maturity across the product lifecycle [24]. This concept is illustrated in **Figure 3** with a typical PLM context, emphasizing Systems Engineering, Industry 4.0 and Internet of Things as subsidiary concepts of PLM [23]. They enable the enterprise to handle and gain benefit from their existing Assets and IT landscape.

Digital Master models serve as a basis and major reference throughout the product development process allowing continuous verification of quality levels. Their process capability can be checked and slightly adjusted by corresponding quality check tools. Based on an integrated product data model, all relevant information can be stored in a self-contained document, managed and operated in conjunction with a suitable PLM integration. By creating a neutral interface, not only cost and effort can be reduced, but also the interoperability of systems, processes and data formats is improved.

Digital Master enables a holistic information integration and improved interoperability in globally distributed product development processes. It replaces the traditional drawing as technical documentation master, which can be derived thereof for information purpose only.

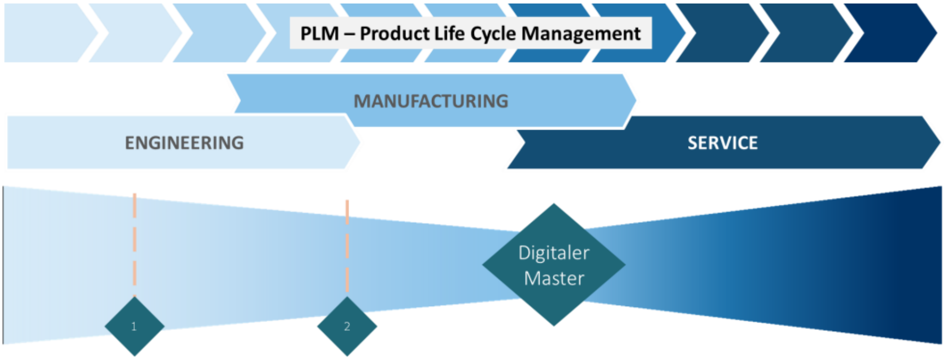

Figure 3. Emergence of the Digital Master [23].

An unambiguous semantic-rich representation of a complex spatial part with 3D model can be generated automatically as an instance of a Digital Master. Realizing this in the context of an extended entrerprise requires three fundamental aspects: integration, management and delivery of information to recipients.

Integration deals with various data segments used to contextually describe the overall product from its different application domains in a Digital Master document. As far as data formats are concerned, it includes CAx system-specific data formats used to natively describe 3D representation, technical drawings or PLM data as well as neutral formats (such as STEP, JT or PDF). These data are retrieved, classified and merged (sematically and contexttually linked) into a container by means of a converter tool. A distinction is made mainly between geometric representation, semantic-rich attributes and metadata as well as miscellaneous documents. Based on this, the data are assigned to a PDF, JT or STEP AP242 XML segment building the main parts of the Digital Master document.

Management provides methods and workflows for the creation of relevant baselines in dedicated time sequences by deriving all necessary data from a backend. A PDM integration provides crutial functions such as entity, privilege and workflow management. This allows a structured, centralized management of Digital Masters while taking into account the complete history of affected product data.

2.2. Usability of 3D master

The usability of the Digital Master based on neutral models spans the entire product lifecycle. The use of the standardized and in industry proven formats 3D PDF, STEP and JT simplifies the integration of information from various authoring systems. As a result, a continuous flow of information and a consistent use of models in all phases of the product lifecycle are achieved without media discontinuities. The concept of Digital Master models supports conventional tasks of the product development, such as requirement identification, design reviews and engineering change management. As for new developments 3D models are usually not available in early stages, rough dimensions of the building space can be defined. In this case, bounding boxes are used as placeholders for components and installation spaces in the Digital Master. Requirements can be added via semantic annotations in the Digital Master, this can also be conducted using mobile devices. In this way, the transparency is heavily improved. Each registered user can participate in this process.

Design reviews are performed in frequent repeatable cycles during the product development. Deriving the Digital Master from the PDM system allows to timely retrieve data on costs, materials and the degree of maturity of the product under development. This information can be visualized directly in the Digital Master using color coding and semantic annotations like PMI. Due to the fact that CAD neutral formats are used, the functionality of CAD viewers is sufficient for this purpose. This helps saving the costs of CAD licenses and eases the use of mobile devices. Defined interfaces enable the integration of 3D models into Office documents and 3D PDF documents. The greatest potential of the 3D master models is provided in the deployment of 3D models with meta-information for downstream processes. Digital Mock-ups (DMU) can't be easily replaced by Digital Master, but improved by the possible simplified data enrichment with metadata [25]. Furthermore, Digital Master enables the deployment of high-performance 3D models and assembly simulations.

In case of tolerancing, the main work usually starts in the mature phase of the product development and is later expanded during the production planning. Holistic view on the tolerances requires an early examination of reasons, assessment of impact and consequences of tolerances. This requirement could be fullfiled by Digital Master under certain circumstances. Such solution concept must resove the following challenges: CAD system dependency, easy translation into neutral formats, method compliance, cost effectiveness and availability of tolerancing know-how in early design phase [23]. That are the pre-requisites for deployment in an Industry 4.0 approach.

Digital Master provided in a certain frequence could yield the following benefits: single (real) master, digital availability, visualization, invest-friendly by standardization. In such way, Digital Master could evolve to an entry point for an automated dimensional quality control in Industry 4.0 systems which need the comprehensive information on environment (Figure 4).

A practical implementation lies on a general use of geometrical dimensioning and tolerances in 3D CAD system and a comprehensive support for the designer on 3D tolerancing. Due to the considerable complexity of such tolerance chains, which is hard to control by a human in a short time, the consistency of singular tolerances must be frequently checked by an appropriate check tool. After the desired status is achieved, CAD model must be translated into a lightweight format (3D PDF or JT). In case of structures, STEP AP 242 could be also used. Finally, such 3D lightweight model must be included into the Digital Master document which already contains the metadata extracted from the PDM system.

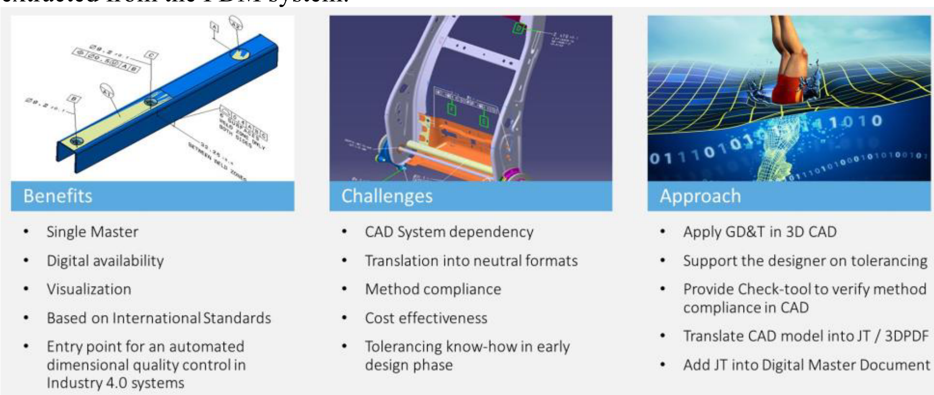

Figure 4. Model-Based Definition with GD&Ts inside the Digital Master Model [23].

2.3. Provisioning of Digital Master

The concept presented here encompasses the elaboration of Digital Master by using standardized and neutral formats, plus the related meta-information. Information from disparate authoring systems can be integrated and made available for use in the entire product lifecycle. The 3D PDF or JT segment facilitates the efficient visualization of 3D product data. Based on viewers, the use of mobile devices is possible. The STEP AP242 segment provides the XML schema to integrate the geometry and metadata. Geometry is embedded, the meta-information is stored in intelligent PDF templates. In an early phase of product development, the annotations from Digital Master could be automatically translated in a formalized requirement specification. The software connection to a PDM system enables proven functionality as elements and privileges management and integrates them into the digital masters. As part of this, also the multi-input converter tool to integrate the information from the various data sources is necessary and should be installed.

This concept significantly saves operational costs by reducing system-specific interfaces and improves the interoperability throughout the entire product lifecycle. The use of standardized neutral formats leads to a reduction in the number of CAD systems to be involved, whereby licensing costs are economized and staff access to information is facilitated. Furthermore, a plethora of software applications is already available for 3D PDF, STEP and JT. All these applications can be distinguished by user-friendly handling and low costs in comparison with CAD systems. The training expense drops dramatically. In the sum, the invest costs are also significantly reduced by implementing Digital Master.

3. Conclusions and Outlook

High interoperability makes an important contribution to engineering collaboration. Several formats made to that end successively deal with challenges of their time. Some of these such as STEP are highly verbose formats, which gradually encapsulate all information necessary to define a product, its manufacture, and lifecycle support. Others are focusing best on lightweight visualization use cases and endure better with increasing size and complexity of data.

Traditional formats like STEP and JT, though, are not capable of supporting the publishing activity in even broader fashion. New tendencies therefore are aiming at strengthening these individual formats through combination with complementary standards or by using document-based approaches. An expanded information model can manage this additional information for the Digital Master. However, in the era of lean and agile, seamless collaboration needs continuous planning.

Unlike STEP or JT, 3D PDF can serve multiple purposes and leverages 3D data downstream throughout the product lifecycle to create, distribute and manage ubiquitous, highly consumable, role-specific rich renditions. 3D PDF is a fundamentally different approach from traditional experience established in product development – it is an exceptionally proficient contextual aggregation of multi-domain and multi-disciplinary product data. The manufacturing community should embrace it as an addition and great improvement to current engineering collaboration standards [26]. All engineering components required for its descriptions are meanwhile published international standards.

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