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Integrated Product and Production Platforms: Towards a Research Agenda

Kristina SÄFSTEN[a,1], Fredrik ELGH [a], Carin RÖSIÖ [a] and Roland STOLT [a]
[a] *Department of Industrial Product Development, Production and Design, School of Engineering, Jönköping University, Sweden*

Abstract. Product platforms have been used as a strategy for manufacturing companies to stay competitive and have provided a means that fulfils the need of agile and demand driven product realisation. However, a link to the production system development is often missing. Knowledge is required concerning how a platform approach can be applied in the production domain and integrated with the product platform. The purpose of this paper is to outline a research agenda for integrated product and production platforms. Based on a literature review and empirical material from more than 50 interviews in five manufacturing companies, state-of-the art and state-of-practice is presented, together with a preliminary research agenda. A flexible, although systematic and structured, approach is needed where the product platform and the production platform are well integrated to support agile, and demand driven product realisation. A product realisation process supported by integrated product and production platforms is expected to support the competitiveness of manufacturing companies facing a market characterized by high diversity and rapid change.

Keywords. platform planning, platform development, digitalisation, integration, boundary crossing

1. Introduction

Manufacturing is the backbone of Europe [1]. To fulfil the customer needs, remain competitive, and at the same time comply with environmental concerns, more attention is needed on the relation between product development and production development. The manufacturing industry need to close the loop between product and production process development in the short-term (for example by ‘design for manufacturing’) as well as longer term roadmaps for products, aligning them with production roadmaps [2]. A concurrent way of working implies that engineers responsible for product and production system design activities are interdependent, where each party is constrained by the decisions and activities of the other party. The topic of integration in product realisation is stressed by initiatives such as Industry 4.0, with emphasis interoperability, i.e. the connectivity between different systems [3].

To master the increasing and changing set of demands and requirements from legislation, customers, and other stakeholders, integrated development of product and production system are required. Despite vast research, integrated product and production

[1] Corresponding Author. Kristina Säfsten, Department of Industrial Product Development, Production and Design, School of Engineering, Jönköping University, Box 1026, SE-551 11 Jönköping, Sweden. E-mail: kristina.safsten@ju.se.

development is still a challenge in practice [4, 5]. As one approach, product and production platforms might be an avenue forward.

Product platforms may be used as a strategy for manufacturing companies to stay competitive and provide a means that fulfil the need of agile and demand driven product realisation [6, 7]. The predominate use of a product platforms includes the development of modules that are used to form product variants which are either predefined [6] or compiled by configuration of the modules [8]. This approach has been successful in some businesses whilst others struggle in their efforts of implementation [9-11]. Some of the identified drawbacks are the amount of time and effort needed in the initial development and that the platforms are hard to continuously develop and maintain as market preferences and/or technology changes [9, 11, 12]. Moreover, a link to the production system development and manufacturing constraints are often missing [13]. A production system is often designed for one product platform and cannot easily be updated to conform with changes during the product platform lifecycle.

Following the idea of concurrent engineering [14] and integrated product development [15], an integrated and cross-functional approach is needed for development of product and production platforms. Some researchers suggests co-evolution or co-platforming as support for the concurrent development of product and production platforms [16, 17]. Others focuses on utilizing models and ontologies to link the product and production systems domains during a product realisation process [18]. However, this research is emerging and there is a need to develop further knowledge on how to concurrently develop product and production platforms to support demand driven industrial product realisation process with ability to fast master changes. To sum up, knowledge is required concerning how an integrated platform approach can be achieved.

The purpose of this paper is to outline a research agenda for integrated product and production platforms. To address this, a literature review and empirical material from more than 50 interviews in five manufacturing companies were used. This made it possible to formulate a research agenda, highlighting future avenues for research concerning integrated product and production platforms.

2. Method and material

The research agenda presented in this paper is based on an analysis of state-of-the art and state-of-practice. The state-of-art was based on the results from a traditional literature review [19]. Key words used in different combinations were product platform, production platform, integrated platform development, integration. State-of-practice was based on empirical material from five manufacturing companies. The companies represent two industrial sectors, i.e., the traditional manufacturing industry and industrialized house building industry. The companies are medium-sized or large and have both product development and production within their premises in Sweden. The companies are part of an ongoing research project, selected to represent manufacturing companies interested in integrated product and production platforms. The data used for the state-of-practice description originates from the initial current state analysis, involving in total 51 respondents. Data was collected by semi-structured, open-ended interviews. The respondents represented relevant functions such as R&D, engineering design, sales, and production. Among the respondents were managers, engineering designers, production engineers, etc. The interviews were carried out from September to November 2020. In total, eleven researchers carried out the interviews. The interview set-up was two researchers, if possible, representing production and product development respectively, and one respondent. To support the interviewers and secure the coverage of topics, a structured interview-guide with open-ended questions was used [20]. The interview-guide was sent beforehand to the respondent, together with information about the project. Each interview took between 60 and 90 minutes, with some deviations. The total interview time was 64 hours and 32 minutes. All interviews were carried out via a digital platform (Teams), recorded, and transcribed verbatim. For the analysis, data from the interviews were combined with internal company documentation such as process descriptions and organisational charts. Analysis of the data followed a traditional procedure for qualitative data analysis procedure including the three steps: data display, data reduction, and conclusion drawing and verification [21]. To validate the results, workshops were carried out at each of the five companies. During the workshops the complied results were presented, and its relevance confirmed by the participating company representatives.

3. State-of-the art

Before presenting the result from the literature review, the platform concept requires a few words. A platform can be defined as "a set of subsystems and interfaces developed to form a common structure from which a stream of derivative products can be efficiently developed and produced" [6] (p. 39). The platform concept is, however, not defined in a unified way. A product platform can be described as consisting of components and modules [6], a group of related products [7], or a technology applied to several products [22]. A holistic perspective on platforms is suggested by Robertson & Ulrich [23], including the following assets categories; (i) components (the part designs, fixtures and tools to make them), (ii) processes (the equipment used to make or assemble components, design associated with production process and supply chain), (iii) knowledge (design know-how, technology applications and limitations, production techniques), and (iv) people and relationships (teams, relationships between various actors, functions and organisations (e.g. suppliers).

3.1. Product platforms

The research in the field of product platforms has mainly adopted an artefact-oriented approach supported by the evolution in Product Life cycle Management (PLM) and configuration systems. This approach has been further supported by Knowledge Based Engineering (KBE) tools for modelling of design knowledge. A process approach based on engineering tasks has been widely used for simulation and optimization and the modelling of tasks to support efficient quotation and order processes has been studied by Elgh [24]. Research on process modelling in engineering design has been conducted for many years, e.g. Shapiro, et al. [25]. A heterogeneous platform description, combining the modular and task-based approaches, which is allowed to evolve seems to be a promising approach for some companies [26]. However, no integrated product and process model exists that gives equal weight to product modelling as to process modelling [27]. The platform approach has been shown to be an enabler for efficient customization, reuse, and production standardization. A question is if companies can stay competitive without implementing a platform or in the future [28]. Yet, for some companies, a platform strategy that builds solely upon pre-defined modules and components is insufficient [10]. A less rigid approach is required which has resulted in the introduction of flexible product platforms [29] and adaptable product platforms [30]. This has inspired the development of the Design Platform approach [26] which is built on a coherent collection of pre-defined and evolving design assets [11] that are structure, managed and maintained for the purpose to support the design of different product variants and adaptation due to changes in, by example, customer requirements, technology or legalisation.

3.2. Production platforms

In current platform literature the consideration of production aspects is fragmented and the guidance in production development through production platform is scarce [31]. Explicit application of a platform concept within the production domain are made only in a few papers. As one example, a conceptual framework for production platform philosophy and platform-based design related to non-assembled products was proposed based on a study within the process industry [32]. By using Quality Function Deployment an integrated knowledge platform including product, process, and raw-material platforms was developed. In another example, product and process platform configurations was evaluated through data-driven discrete event simulation [33]. Production platforms were also considered in a thorough literature review in which a holistic decision framework for product family design and platform-based development was proposed [34]. The framework encompassed the functional, physical, process and logistic domains and calls for a holistic platform also including manufacturing, production, and the supply chain. Furthermore. the concept of production platforms was investigated in a case study including four projects at one manufacturing firm [35]. In this research, five challenges related to production platform development were identified (1) a lack of consistency and coherency in vocabulary and development processes, (2) misalignment of participant knowledge on platforms and project scope, (3) miscommunication between departments at the company, (4) lack of examples regarding documentation platforms, and (5) lack of research and tools in current production platform research.

3.3. Integration through technology

Digitalisation is a way of establishing a link between product and production platforms. A platform may contain different types of digital tools, data repositories and data management systems, including for example Computer Aided Design (CAD), Computer Aided Manufacturing (CAM), Finite Element Analysis (FEA) along with data management systems such as Product Documentation Management (PDM) and Enterprise Recourse Planning (ERP). These systems are often referred to as Information and Communication Technology (ICT) and are used throughout the whole life cycle of the products. Together with the processes and methodologies an environment commonly known as product lifecycle management (PLM) is formed [38]. PLM is product centred and is about coordinating ICTs, processes, and methodologies throughout the life cycle of the products. The situation has recently (latter 5 years) become more complex due to the emerging technologies of Industry 4.0. The basic technologies of Industry 4.0 are the Internet of Things (IoT), cloud services, big data and analytics [36].Via many sensors, data is continuously gathered and processed into useful information to be provided at the right time and place. With access to the information from the whole lifecycle better decisions in technology, product and production development can be taken. This can be both decisions taken by autonomous systems as well as buy human operators. This will mean a major step in the development of PLM. Currently, different strands of research into PLM are being conducted, partly related to the megatrends in society: circular economy [37], cloud based data [38], and artificial intelligence (AI) [39].

3.4. Organisational integration

There are different types of boundaries in product realisation processes which hinder problems solving and communication. Several means for integration across boundaries are explored, both in research and practice. Integration can be defined as an interaction process involving collaboration or co-operation and exchange of information [40]. The need for integration varies with the nature of the product realisation process. A higher degree of uncertainty and complexity, requires a higher degree of integration [41]. So far research has focused on integration between product development and production [4, 5], rather than between product and production platforms. Several researchers have focused on various integration mechanism, such as standard and rules, plans, signoffs, teams, mutual understanding, etc [42, 43]. These integration mechanism can be categorised as being related to either technology or organisation [44]. As mentioned in the previous section, CAD, CAM, and other ICT are typical examples of technological integration. In this section focus is on organisational integration, related to structure, people, and culture. In this vein, one way to support actors to cross different boundaries and establish the required integration is through the use of boundary crossing strategies such as boundary objects [45]. Boundary objects can be defined as artefacts (things, tools) that interconnect actors from different domains [46]. Examples of potential boundary objects in a product realisation context are Failure Mode Effects Analysis (FMEA), Design for Assembly (DfA), drawings, prototypes, visual representations, and simulation [47-50]. Other essential elements of boundary crossing are boundary encounters (meetings, visits, etc.) and brokers (individuals moving between different communities) [46].

4. State-of-practice

The current state-of-practice is based on 51 interviews in five manufacturing companies.

4.1. Product and production platforms

The companies currently have no formal product platform strategy based on predefined modules and components. As expressed by two respondents in one of the companies when discussing if product platforms are known and used, "No, or I know it even though I do not know." (Design Engineer) and "… we are bad at it, from my perspective…" (Project Leader). However, the industrialised house builders described that a set of predefined components were used as a foundation when developing customer-specific products. The traditional way of platform development poses challenges as it requires high investment at the same time as the companies need to fulfil unique requirements, be able to quickly introduce new technology, adapt to new legalization and sometimes optimize the product performance. Even if a formal product platform strategy based on predefined module and components was not used, reuse of technical solutions, models, engineering methods and knowledge in product development was common. In all companies, reuse of standard components, component libraries in CAD or PLM systems, reuse of existing product models, and reuse of knowledge (complied in documents such as guidelines and lessons learned), were expressed. However, the reuse of solutions, models, engineering methods and knowledge was dependent on the individuals and all these assets are only partly structured, shared and managed as a coherent unity in a systematic way in all companies.

Related to the production platform concept, both explicit and implicit considerations of the concept was studied. A long-term production perspective was considered as important within all companies, which motivates the relevance of a production platform. However, no clear holistic long-term plans were explicitly present. Three of the companies had established long-term plans related to automation. Production platform was not a used term or concept within the companies and the term was understood differently between the companies. Modularization and standardization of production assets were, however, applied in the companies to different extent. Standardization in requirement specification, work descriptions and types of production equipment were applied. Related to reuse of knowledge, the companies had procedures and routines to document lessons learned e.g., after a project ended. Mainly, this included product development, but also to some extent production development related activities.

4.2. Technological and organisational integration

A variety of tools and systems were in use at the companies. However, they were mostly isolated "islands" with none or little digital interoperability between them. But there were also examples of digital transfer solutions between engineering design and production through for example the business system. A common situation in the companies was that when a product has been defined by engineering it was transferred manually to the productions IT systems. In practice, this formed a parallel product structure for the purpose of manufacturing the product and a risk of errors was introduced in the information transfer. Furthermore, it became difficult to handle changes since two parallel and unintegrated structures needed to be updated. A change in the production was not automatically propagated to engineering and vice versa. The engineering companies perceived a need for integration between their parallel representations of their product structures, partly because the need to keep information on every individual physical product constantly up to date. As an example, there was a need for traceability of software for individual products already out on the market back to engineering.

Since established and well-defined product and production platforms were not explicit in the companies, the organisational integration between product development and production was in focus during the interviews. Focus was on successful and less successful ways of integrating product and production development, using various work procedures, engineering tools, and means for communication. The companies had a product development process intended to support the work. Cross functional project teams were mentioned as one common way of organisational integration. Some the prescribed activities in the development processes, such as design reviews, prototypes, test series was perceived as specifically useful. An essential element to succeed was the joint work, and as one of the respondents expressed: "we need to do things together". To succeed with integration between product development and production, a standardised way of working was emphasised, as was access to relevant knowledge.

5. Integrated product and production platforms – towards a research agenda

The aim of this paper was to present a research agenda for integrated product and production platforms. Based on an analysis of current knowledge, a preliminary research agenda was developed structured around the two main research areas: platform planning and development, and means for integration, see Figure 1. To support product realisation, it is also required that the product and production platforms are integrated into the product realisation process, and that a use-and-learn loop is established.

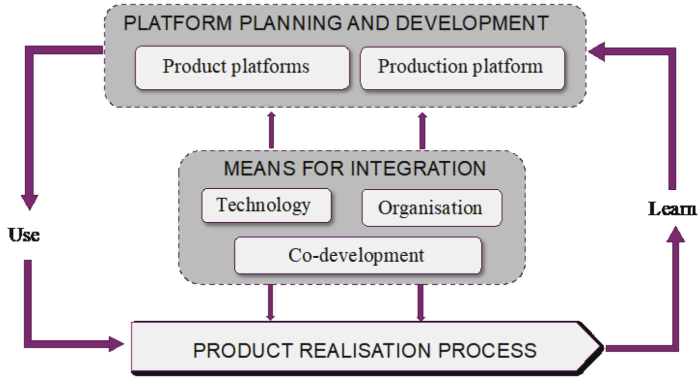

Figure 1. The main elements of the preliminary research agenda related to integrated product and production platforms.

5.1. Platform planning and development

In the research area, platform planning and development, a need for changeable product platforms is pointed out, as well as an established production platform concept.

There is a need for knowledge, methods, and tools for improved ability to design and adapt products when needs and requirements from different stakeholders rapidly change and/or new technology rapidly evolve. At the same time, the producibility of each design must be ensured. Changeable production systems have potential to support flexibility, however, as more product options are possible, the more challenging are production preparation and the process to ensure, and improve, producibility of product variants and unique solutions. When efficiency in production cannot be reached by means of standard modules and components, other means are required to guide, assess, and improve both product design and producibility. The producibility can be supported by means that continuously guide the development to ensure high compliance with the production system, or by means to assess one or many design solutions, i.e., synthesis or analysis approach. In summary, flexible and adaptable, although systematic and structured, product platform approaches are needed, improved co-development supporting alignment of the product platform(s) with the production system is critical, and the product platform should be expanded to include different engineering means (assets) to guide, assess and improve producibility of each design.

The production system design involves interrelated functional, structural, and hierarchical system aspects to satisfactorily cover unique and case-specific design decisions on changeability objective, drivers, enablers, extent, and level of implementation. In line with [35, 51], a need to determine the appropriate production platform for each company, to specify its structure and content as well as quantify the potential of applying production platforms, was identified. This is a complex design activity, which potentially can be supported through a production platform. A production platform enables a production system structure through visualised assets. It bridges the manufacturing strategy to the production system design and, thereby, support a long-term view on production development. The study presented in this paper, confirms the challenges identified by [35] including lack of consistency in how the production platform term is used and applied, that the participant knowledge on platforms and project scope differs within the companies, and a lack of support to structure and describe production system assets in order to enable standardization and reuse. By identifying its platform assets and architecture, including sub-systems and components, a production system can be designed and modified in different combinations to handle variations and enable customization. A need to determine the appropriate type or amount of production platforms for a given company, and to specify as well as quantify the potential of applying production platforms has been identified [35, 51]. Another identified area of potential is the modelling of production platforms and subsequent mapping to corresponding product platform models [35].

5.2. Means for integration

In the research area, means for integration, three subareas are highlighted in the research agenda: technology-related integration through homogeneous PLM, organisational-related integration through boundary objects, and co-evolution of product and production platforms.

There are extensive challenges in keeping all product data available at the right place and time so that appropriate decisions can be taken about the product and the production system. Digitalisation can widely improve the information retrieval capacity and limit the reliance on the people involved. As mentioned in chapter 3, many different tools and systems are used during the product life cycle. Item-centred PLM allows access to for example the simulation results when decisions on products and productions are taken. It is also useful to get an elaborate view on all requirements that apply to the product being developed. One of the challenges with PLM systems is that it spans the whole lifecycle and thereby many different functions in the company such as market, legal, purchasing, logistics, engineering, production, and quality. All these functions use their own systems causing interoperability problems [52]. To date, there is no complete PLM system that can claim to span all functions in the company. Every company is faced with building the IT environment on a level of integration that is right for in the company. This creates many challenges from an IT perspective but done right it will lead to a more integrated IT environment saving time and reducing the number of errors that can occur with manual data transfer between the different systems.

Product and production platforms integration implies a high degree of novelty for the actors which need to develop new solutions, practices, and methods to solve their problems across domains. However, research on what boundaries that need to be crossed and how this could be supported is scant. Different boundaries require different boundary objects to establish processes and mange knowledge across a boundary [47, 53]. Boundary objects are contextual, i.e., they are not effective in all contexts and depend on the boundary that they need to deal with. To be a boundary object, the object needs to possess certain characteristics as mentioned above. Therefore, it is interesting to know how and when certain objects during the product and production platform integration process become boundary objects. Apart from integration of product and production platforms, there is a need for integration of these platforms in the product realisation process to support agile and demand driven product realisation.

Co-evolution of product and production platforms can be enabled by platform-based co-development [54]. One such example is reported by [55] where practices for platform-based co-development were described both from a project and a process perspective. A structured way of working was applied in the platform-based co-development project, and the organisation included redefined responsibilities to enable the new way of making product and manufacturing development. The specific development process required not only coordination between the product and production development groups but required joint design due to tasks being highly interdependent between design domains.

6. Discussion and conclusion

The purpose of this paper was to outline a research agenda related to integrated product and production platforms. As we can see, based on the presented state-of-the-art and state-of-practice, there are several potential avenues for research related to integrated product and production platforms, both concerning platform planning and development and integration. Product platforms are more established, both in the literature and in practice, compared to production platforms. The product platform is considered fundamental in future product realisation, requiring increased structure and at the same to a global dimension to capture anticipated challenges [56]. A need to establish the production platform concept is needed, aligned with current product platform concepts. The ability of reusing and recombining both organizational and technological production system assets are essential for manufacturing companies in the future [57]. Despite that, current knowledge about production platforms are limited [31]. However, production platforms are sometimes discussed as part of more general platform planning approach [39]. With this approach the integration is built into the approach, requiring that the interactions between the product and production is carefully co-developed [58]. The importance of developing integrated platforms are highlighted [59, 60], an in line with this it is suggested that future efforts might focus on integrated platform development to support systematic product family development [12].

The other research area, means for integration, aims at developing knowledge related to the integration process, involving questions concerning when, how and what to integrate. Integration can be achieved with support from various integration mechanisms [4, 5]. Focus can be on technological means (digitalisation) and organisational means for integration [44]. Integration can also be supported through co-development of platforms. The key areas related to digitalisation in product and production platforms are interoperability between different systems and data sources in the manufacturing companies and keeping information on requirements and the capability of the production system up to date and available to the stakeholders. As one example, the interoperability between the different bills of material (BOM) has emerged as important. Based on the presented state-of-practice and state-of-the-art, the integration of the different systems into a more homogeneous PLM is suggested. As an organisational mean for integration, boundary crossing through elaborated use of boundary objects are identified as a potential avenue forward. Boundary objects are contextual, i.e., the object needs to possess certain characteristics and to be considered in conjunction with the other essential elements of boundary crossing [46]. More understanding is needed concerning boundary objects in a product realisation context, how and when certain objects can become boundary objects, and how to maximise their effect through an elaborated boundary crossing strategy.

To conclude, despite the effort in platform planning and development as well within integration in product realisation there are still several areas that need further research. Related to the research area platform planning and development, a need for changeable product platforms was pointed out, as was an established production platform concept. Related to means for integration three subareas were highlighted: technology-related integration through homogeneous PLM, organisational-related integration through boundary objects, and co-evolution of product and production platforms. These are areas that need further research.

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