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Platform-based Production Development

Towards platform-based co-development and co-evolution of product and production system

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Abstract. Platforms as a means for applying modular thinking in product development is relatively well studied, but platforms in the production system has until now not been given much attention. With the emerging concept of platform-based co-development the importance of production platforms is though indisputable. This paper presents state-of-the-art literature on platform research related to production platforms and investigates gaps in the literature. The paper concludes on findings by proposing future research directions.

Keywords: Platform-based co-development, Platform-based Production Development, Integrated Product Development

1 Introduction

Over the years, modularising products has been seen as means for increasing the efficiency of product development, products in general as well as the manufacturing process. The research field is documented intensively within the research field of Mass Customization, and methods for product modularisation, product family design, and product platform design have been developed under such names as Modular Function Deployment, Product Family Master Plan [5], and Extended Product Family Master Plan. One of the key outcomes of using these methods is awareness of a product architecture i.e. the structured mapping of functional elements in the product, the mapping of functional elements to physical components, and specification of interfaces among product elements. The common elements in an architecture can be considered to constitute a platform that may enable cost effective reuse across products if properly designed [2]. Competitive market conditions demand products manufactured with the lowest possible cost, and hence a need for a more holistic understanding of the product realisation process must be incorporated in the architectures. In other words, the product must not only be designed for the consumer, it must also be designed for manufacturing [8], and this creates a need for integrated product development and concurrent engineering.

One emerging concept that seeks to extend integrated product development is called platform-based co-development and co-evolution of product and production system [15] (later referred to as platform-based co-development). The intention is to use one

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common platform for both product and production development or align the product and production platforms. Thus, the communality that constitutes the platform is more complex than just considering common product parts.

This paper presents a review of literature in the research field of platform-based co-development and identifies gaps in literature. To frame the paper, the following two research questions are used: *(1) which research exists concerning platform-based co-development, and (2) how can this be classified in order to identify gaps?* The paper concludes on the two research questions by arguing for future research directions within the field of production platforms and platform-based co-development.

2 Method

The literature identified for this study is found by searching the databases of Web-Of-Science, SpringerLink, ScienceDirect and Scopus in a combination of block searching and pearl growing. The search string was defined rather broadly with exact search phrases relating to production platform development, and combined with specific terms that relates to production development. Exact phrases used was for instance "Process Platform*", "Manufacturing Platform", "Production Platform", "Platform-based development", and specific terms used was for instance “Manufacturing”, “Production” and “Design”. If available by the search engine, filtering according to the research field and keywords was done to limit the number of search hits. In total 13 keywords were used such as “Platform development”, “Platform approach”, “Platform-based” and “Platform strategy”.

2.1 Classification

A classification is created for differentiating focus in the identified literature. Due to space limitations of this paper, the citations selected to present state-of-the-art is though not exhaustive. They rather serve as an illustration of one part of the classification, and thus as an illustration of the type of focus appearing in state-of-the-art literature related to production platforms and platform-based co-development. The full classification distinguishes between research focus, application focus and research maturity but only research focus is considered for this paper. This focus is elaborated below.

Regarding research approach, studies can be differentiated by their origin in either problem base or theory base, which influence the research approach [9]. Both approaches give academic contribution, but the former does it in the sequence of (1) analysis (i.e. exposure of structure, causality, empirical knowledge), (2) diagnosis and (3) synthesis (i.e. generation of solutions, assessment of consequence and selection) [9]. The latter gives academic contribution by (1) synthesising on theory (i.e. building structure, internal consistency etc.), (2) propose models and (3) conducting theory analysis (i.e. validity, usefulness, external consistence etc.) [9]. Seen from a viewpoint of Design Science, the output of research is artefacts that are classified into constructs, models,

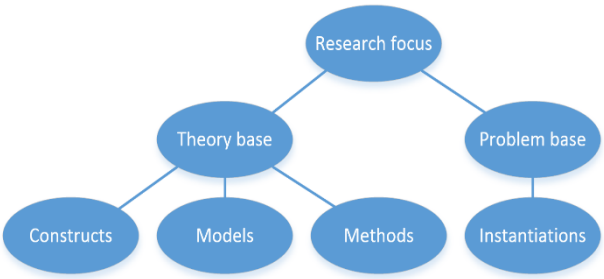

Fig. 1. Illustration of classification used for differentiating literature

methods and instantiation but not necessarily all of them in each contribution [19]. This study relates research approach and research output in the literature classification by considering literature focusing in construct, model and method creation as theory based research, whereas literature focusing on instantiation is considered to be research within a specific problem base (Fig. 1).

3 State-Of-The-Art

3.1 What is a platform?

The platform as a term is not new and has been used in several contexts with several meanings. This study focuses on product and production development, and in that perspective Baldwin & Woodward [2] report use of the platform term as early as the 16th century with meaning as 'a design, a concept, and idea; (something serving as) a pattern or model'. In more recent time, several platform definitions have been proposed in the area of product development research such as "*collection of assets that are shared by a set of products, including components, processes, knowledge, as well as people and relationships*" [18], or "*set of subsystems and interfaces developed to form a common structure from which a stream of derivative products can be efficiently developed and produced*" [13]. The common way of grasping product platforms is however component/part communality, but some definitions do hence also include other aspects such as technology, people and relationships. Thus, production aspects—such as production technology, process, operations, and resources—may also set the foundation for identifying or designing platforms. Such kind of platforms is referred to as production platforms [17]. In fact, studies show that the basic principle of platforms is the same across research fields [2]. This is referred to as the *architecture of platforms* and more specifically …''*platform architecture displays a special type of modularity, in which a product or system is split into a set of components with low variety and high reusability, and another set with high variety and low reusability*" [2]. The first set is the platform and the second is argued to have no generic name but can be referred to as 'the complements' of the platform [2]. Research related to product development has however called the first set of components *Standard design* and classified the compliments into *Design unit, Future design unit* and *Future std. design* [5]. Even though the basic principle of a platform seem similar, the two examples above show minor differences since one argue that platforms consist of standard modules and hence no variety, whereas the

other is less unambiguous and states that a platform consist of modules with low variety. However, platform elements and its complements are distinct modules in the system architecture, and their interoperability is made possible via interface specifications [2], [5]. According to the classification, the above studies of platforms are considered research focusing on constructs and early model creation.

3.2 Platform as a concept for development

Similar research focus is present in other studies related to platform-based co-development but more detailed constructs creation exists. A selection of this literature is reviewed below.

Three evolution paths of relevancy towards executing platform-based co-development are identified with starting point in dedicated co-development i.e (1) *product platform based co-development* (only product platforms), (2) *production platform-based co-development* (only production platforms) and (3) *platform-based co-development* (utilising both product and production platforms) [14]. Dedicated co-development is considered as traditional development of product and production system with some degree of collaboration, but without the use of platform thinking [15]. The opposite approach that encourages such co-development is the traditional engineering which is also referred to as *Over-the-wall-engineering* and *Sequential engineering*. Platform-based co-development can hence be considered as an integrated product development approach that can be ranked alongside or as a branch of concurrent engineering where cross-functional work and information sharing is in focus. An important purpose in co-development processes is to create and intelligently visualise boundaries and capabilities for product and production system design such that variety is only present where it is desirable and acceptable [10].

One aspect of platform-based co-development is product platforms for product family development. This aspect is relatively well-studied and Jiao et al. [8] present a heavily cited collection of research conducted in this field. Regarding the production aspect of platform-based co-development specific definitions on production platforms has not been identified in the study for this paper, but Johannesson [10] emphasize the fact that product and production are co-equal systems, and hence such definition will have significant similarities or be equal to the product platform definitions just presented. Termwise platform-based co-development was first coined by Michaelis [16] and later elaborated [15], but the research can in principle be traced back to the product platform definition by Meyer & Lehnerd [13]. This definition advocate co-development since communality is not necessarily limited to product information but also include support for product realisation information, and hence support for reuse of production system assets. This is consistent with Johannesson [10] who emphasize importance of reusing assets by means of product and production platforms.

Research on *Process Platform* is considered research encouraged by the inclusion of production aspect in product platform development, and hence something that relates to a production platform. Conceptually Process Platforms was coined in Jiao et al. [7], and later the term was elaborated by e.g. Zhang [25]. The literature identified on process

platform is focused around—but not limited to—generic product and process structures, generic routing, generic planning and generic variety representation [20]. For instance Zhang & Rodrigues [24] used a tree unification approach to create an algorithm for identifying generic process elements in known production system data. The algorithm was tested on industry data that contained 30 different process trees with operations and operations precedence for production of vibration motors. From these 30 process trees, 13 basic process trees were identified and merged into one generic process tree. With the perception of platforms reviewed above, such generic process tree constitutes a platform and the remaining processes can be considered as compliments of the platform. The narrow scope of the algorithms does though not support a complete identification of production platform elements, but rather—as indicated by the name—identification of a process platform.

3.3 Representation and methodologies for platform development

An important aspect of Platform-based co-development is communication through models and visualisation techniques [10] (later referred to as representation). By considering identified literature on representation according to the classification (Fig. 1.), then this literature can be considered to focus on model and method creation. Representative selections of this literature are reviewed below.

A part of the research identified on representation focus on platform as concept i.e. conceptual models formulated according to basic constructs, definitions, relationships, and functionalities [21]. Other research deals with representation techniques for a platform design methodology with various scopes and degrees of abstraction on co-development [12], [24]. This indicates that platform design in a co-development process must have focus on different co-development aspects, different abstraction and different detail levels.

Baldwin & Woodward [2] presented three basic representation techniques that can be used to investigate relationships between variables of any types of platform i.e. Graph representation, Design-Structure-Matrix and layer maps. Graph representation is for instance used in the tree unification algorithm [24], and layer maps are used for communicating product platform elements in [5]. Such visual representation of relationships for identification of possible platform elements is in this sense considered tools for platform design and hence something serving as support for methodologies.

Furthermore, dynamic models are proposed to represent relevant processes and their behaviour [21], and can generally be classified into visual diagrammatic process language and programming process modelling [21]. The latter in itself is reported to have strong limitations in readability and comprehensibility [21] and hence not a relevant for co-development alone. The dynamic models are for instance used for process platform configuration [23].

In the area of product development, Harlou [5] has managed to enable visualisation of product data and structure for easy product family development and evolution. The research covers both constructs, models, methods and applications, which is operationalised in the tool called “Product Family Master Plan”. The tool builds on ‘’Theory of

Domains'' and the ''Chromosome model'' created by Andreasen et al. [1] for visualisation of the product composition, and to structure relevant product development information into three views (Customer view, Engineering view and Part view). The customer view decomposes functions as perceived by the customer, needed in the product, which are related to engineering organs (Engineering View) and physical parts of the product (Part View). The composition structure for each view is referred to as a "Part-of" and is combined with a classification-like approach called the "Kind-of". Later research extended this tool to cover production information [11]. Some researchers argue however that these models lack support for production system design [15], and hence also co-development. One argument is that these modelling and visualisation approaches combine the existing product structure and manufacturing process—and thereby address the production of the product—but not the design of the production system itself. The models do thus not completely support co-development of product and production system development, but they provide an elegant way of model existing functional elements and relate them to other existing product modelling domains. Hence, the tool model the architecture AS-IS but does not provide TO-BE.

Other research seeks with similar approach to overcome the representation challenge by using a so-called Configurable Component framework [12], [15]. Configurable Component is an object-oriented modelling technique that can be used as building blocks to model technical systems [3]. One central part of a Configurable Component is a function means tree that can capture the intention of the designed technical solutions. Initially the framework was intended to the product domain, but later research has proposed to use it in an integrated model for co-development [14], [15]. The integrated model by Michaelis [14] presents with a relatively high abstraction level both product and production system in three domains (i.e. function, solution and component domain), and related them to each other through a production process domain. The production process domain is here fabrication operations and assembly operations, which is referred to as *operations for integration of features* and *operations for integration of parts*. The research based on Configurable Component and the chromosome model from above origins from design of Theory of Technical Systems created by Hubka [6].

Although not based in Theory of Technical Systems, other research on representation techniques exist related to platform-based co-development. Zhang et al. [22] propose for instance an object-oriented language that is based on Unified Modelling Language to represents a process platform. In this work, the author emphasizes that not only platform structural information is represented but also product and process knowledge (in form of selection and planning rules). Later this research has been extended to the dynamic Object-Oriented Visual Diagrammatic Modelling Language presented in Zhang [21]. Petri-nets have also been studied as a dynamic modelling language for process platform-based production configuration [23].

4 Discussion on research gaps

The state-of-the-art literature reviewed above found focus in literature on constructs and representation techniques with various scope and abstraction level. Regarding design methodologies building on profound constructs and representations models, much

literature is identified on product platform development. However, regarding production platforms only methodologies with limited scope exist. Some of them cover method development and instantiation [24] but build on narrow constructs and models. Hence, the current literature lacks maturity for a comprehensive method creation on production platform development.

Literature identified on production platforms seems clustered in two groups. The review indicates that some research has strong base in design of Theory Of Technical Systems and have focus pointed at creating constructs and representation which are refined through industry case studies [12], [15]. In such research, communication through visualisation is given importance. Other literature indicates focus on simple constructs but seeks to analyse them with comprehensive mathematical representation models which are validated and used for optimisation with industry data [23], [25].

Since the optimal design of a production system involves many complicated considerations, one can argue that such challenges are not possible to solve with only mathematical optimisation. One of the reasons is that the solution space to consider becomes large for even simple product designs because of entangled relations between product and production system. For example, designing assembly systems requires consideration on product design, assembly sequence, assembly system configuration, assembly line balancing etc. Furthermore, the life cycle of factory related elements are usually longer than the product life cycle, and will require the solution to be dynamic for coping with e.g. fluctuation in demand, capabilities etc. [4].

5 Conclusion

Some of the findings from this study are that constructs, models and methods on production platform design and platform-based co-development are rather weakly defined in literature. Comprehensive conceptual studies have been made with either focus on constructs and models, or models and methods, but these studies must be aligned and put into context of industrial problems. Hence, there is a need for a reference model giving holistic understanding of production platforms to enable creation of methodologies for co-development. Such research would put forward a “language” for discussing platform-based production development and platform-based co-development.

Different engineering disciplines are utilised for fully defining and designing a production platform in industry context, and hence communication of data is an important aspect. Diagrammatic languages that visualise needed data on different abstraction levels and details levels is important and must be investigated further. We envision such research can enable creation of information models for use in co-development tools.

Algorithms for identifying communality and relations were identified in the review. We consider this as an important preparation task since normally new design concepts build on previous knowledge, and hence communicating existing and potential commonalty may be a good input to make platform design process manageable. The current algorithms are though narrow in scope, and we suggest that case-studies must conducted to investigate which types of communality that are relevant to search for i.e. which kind of communality is value adding for specific companies, industries, geographical locations etc.

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