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INTEGRATING PRODUCT AND MANUFACTURING SYSTEM PLATFORMS – EXPLORING A CONFIGURABLE SYSTEM APPROACH

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1. Introduction

Platform strategies are a common approach to increasing companies' competitiveness in the manufacturing industry. They depend on proper descriptions, especially when the platform is technical and complex. This paper explores an integrated platform description of the product and the manufacturing system. It adopts a systems view of those two artifacts. Both systems are intended to be configurable to cover the variability of the systems concerned, therewith constituting a platform description. The integrated description then facilitates defining a platform strategy for the product and manufacturing system. The theoretical approach is based on the so-called Configurable Component (CC) concept, which allows for the representation of the two artifacts, product and manufacturing system, on multiple layers of abstraction and granularity [Johannesson and Claesson 2005, Gedell 2009].

Empirical data for purposes of exploring the approach is supplied by a qualitative study conducted at two second-tier suppliers in the manufacturing industry. It is postulated that the platform description may facilitate the work of engineers from different disciplines involved in concurrent development projects. More specifically, the study aims at identifying issues and challenges in the collaboration between engineering design and the branch of manufacturing concerned with the designing and planning of the manufacturing system. In order to account for the theoretical approach and the qualitative nature of the study, the following research questions were formulated:

- How do engineering design and manufacturing collaborate in concurrent development projects?
- How are platform questions managed in concurrent development projects?
- What unresolved issues and desired improvements exist in the collaboration between engineering design and manufacturing?
- How can the Configurable Component concept help solving the identified issues?

The first two questions aim at gaining an understanding of the mode of collaboration and platform questions, respetively. Questions three and four allow for a discussion and interpretation of the empirical data in the context of the chosen systems approach.

Following a delineation of the industrial and scientific context of this paper, the study, the CC concept and the theoretical approach are described. The findings, both empirical and connected to the theory, are then presented and discussed in the following two chapters. Finally, this results in a conlusion.

2. Industrial and scientific context

An integrated platform description addresses the needs and challenges of those engineering functions concerned with planning and design. The mode of collaboration can, among other things, be affected by how companies describe and define their platforms.

2.1 Designing and planning in engineering design and manufacturing

In manufacturing organizations, one can find different setups and terms for the functions directly involved in the design and manufacturing of a product. They are usually identified along the lines of *marketing and sales, engineering design and manufacturing* [Andreasen and Hein 1987, Chase et al. 1998]. The way these functional units interact has originally and often been represented as sequential and stepwise. However, in any industrial setting, tasks are carried out concurrently. Moreover, collaboration or feedback between functional units occurs before and after each step. The motivation for this concurrent mode of operation is the attempt to increase quality and shorten lead times [Prasad 1996]. Various approaches have been developed to achieve more concurrent processes. They are embraced by the terms *simultaneous* or *concurrent* [Evans 1996, Prasad 1996] and *integrated product development* [Andreasen and Hein 1987], respectively.

From an engineering perspective, it is interesting to examine the mode of collaboration between engineering design and manufacturing. That is because each functional unit relates to a technical system that needs to be designed, refined, planned, configured or maintained with its corresponding behaviors and processes, i.e. the product and the manufacturing system, respectively [Hubka and Eder 1992]. These two systems affect each other's properties and behaviors.

Manufacturing is responsible for two sets of tasks or activities: Beyond the executive activities of monitoring and conducting the ongoing production, manufacturing is also concerned with designing and configuring the manufacturing system and planning the related processes. On the manufacturing side this second set of activities accounts for harmonizing the numerous requirements of the product and of the manufacturing system (with its related processes). Therefore, this article explores these designing and planning activities. Among the most relevant activities in this context are fixture and tool design, rearrangement of machines and manufacturing resources, and process planning.

2.2 Platform strategies

The concept of platforms is a prevalent approach to the challenge of developing profitable products or, seen in a wider sense, achieving successful business of a manufacturing company. Adopting a platform strategy often aims at exploiting benefits of scale as well as balancing distinctiveness and commonality across products. [Robertson and Ulrich 1998]. From an engineering perspective, utilizing platform strategies can mean the reduction in the reworking of already working systems. In turn, this can provide engineers with more time for unique and value-adding development tasks.

Generally, two prevailing extremes regarding the concept of a product platform can be identified. First, a physical perspective can be taken. In it, the platform is represented by parts or assemblies the product is composed of. Second, a product platform can be seen more abstractly "as the collection of assets that are shared by a set of products", including components, processes, knowledge, as well as people and relationships [Robertson and Ulrich 1998]. In accordance with this second perspective on platforms the definition can be widened to cover the design of the manufacturing system and its related processes as well. While many gradations of the level of abstraction are conceivable for a platform strategy, an intermediate step based on a more conceptual and functional system approach can be defined. It is closely related to seeing a platform as "a set of subsystems and interfaces developed to form a common structure" [Meyer and Lehnerd 1997], adding to it the functional considerations of the structure. This definition is the one used this paper. Figure 1 illustrates the described levels of abstraction for a product and manufacturing system platform strategy.

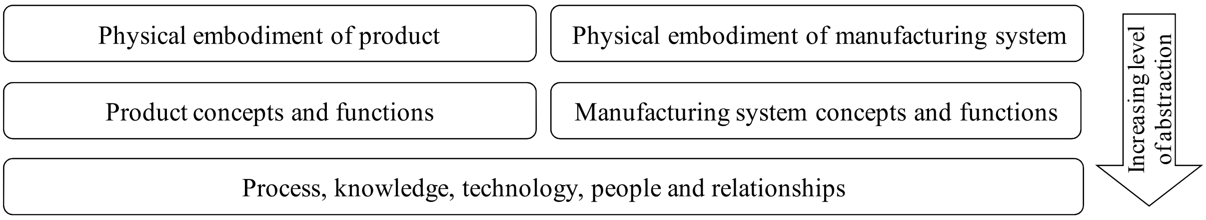

Figure 1. Levels of abstraction in platform strategies

Production resources are generally reused across products. In the context of configurable products, this means that a specific production process must exist for each product configuration. Thus, the production system and the related processes have to be configured to account for the variability of the products. Based on a suitable strategy for a platform, a purposeful description of the product components, subsystems, interfaces, and processes steps to be reused can facilitate the management of the product and the manufacturing system as well as process variety.

2.3 Platform descriptions

Because platform strategies based on physical parts incorporate insufficient flexibility for some companies, van Veen (1990) proposed a more abstract and easily configurable platform description, in the form of generic *bills of materials*. This approach enables the description of large varieties of product types and structures by defining products as *sets of product types* instead of defining *individual product types*. Männistö et al. (2001) propose a similar concept. They describe a *master bill of materials*, a generic description of many product variants that can be defined and manufactured based on the platform. Finally, Johannesson and Claesson (2005) propose a generic framework for describing configurable products and, thus, product platforms, combining a function-means and parametric modeling approach. This so called Configurable Component concept, developed further by Gedell (2009), can be applied for platform strategies on any systems level. It is the platform description used here in this paper. It is further explained in the following chapter.

3. Research approach

The overall research approach was first to conduct an explorative study with the intermediate goal of identifying issues in the interface between engineering design and manufacturing. The results from this study were then contrasted with the capability of the CC concept to manage or solve the issues identified.

3.1 Explorative study

The explorative study was carried out examining two manufacturing companies. Both companies are second-tier suppliers for the automotive and aeronautic industry, respectively. The study began at the aeronautic company. The subsequent part of the study at the smaller automotive company was conducted to supplement data from the first round. Moreover, the second round was intended to discover differences due to size of company, type of product or industry. Thus, the second round examination was carried out with the insights from the first one in mind. The sources of the data collected were company documents, i.e. flow-charts or process maps, and interviews with engineers.

The organizational sheets examined provided the necessary understanding of how functional units and their subdivisions are supposed to carry out their collaboration. More specifically, the sheets provided information regarding during which stage in product development projects information was to be exchanged, which tests were to be conducted, and what documentation was to be approved. For both companies these sheets were generic for all product development projects.

A total of eleven engineers was interviewed, eight at the aeronautic and three at the automotive company. Two design engineers, a design process automation specialist, two lead requirement engineers, a manufacturing and facility planning engineer, and a lead manufacturing engineer were interviewed at the aeronautic company. The two design engineers and the lead requirement engineers

were interviewed in joint sessions in both interviews. This provided each interviewee the chance to give an individual answer and to add his own thoughts. The interviewees from the automotive company were a design engineer, a material expert, and an unaffiliated engineer deployed for the development of new product and process technology.
The interviews were conducted with the help of an interview guide containing predefined questions. The questions were grouped under the following topics: design and manufacturing preparation process, information exchange, platform, supplier, IT support, and the traceability of information. The interviewees were also given the chance to answer freely. Though not necessarily exact answers to the questions, these observations provided valuable information. Moreover, the interviewees were asked to exemplify their answers using one particular product development project. Answers related to other projects were accepted as a chance to broaden the view with respect to how projects differ. Each interview lasted approximately one hour.
The audio-recorded interviews were transcribed in full and exactly for purposes of analysis. The responses were analyzed as to what question they actually answered. They were then rearranged in order to correspond with one of the topics. This was done in a joint effort by two researchers to limit individual-related bias. In the same step, statements that evidently were not in the context of the research questions were removed. Also, answers from the interviewees were compared for each topic to identify reappearing statements. This was done to establish the consistency of the data. Finally, the essential statements, i.e. those with bearing on the first three research questions, were collected. They are presented in the following chapter.

3.2 System modelling with Configurable Components

The Configurable Component concept is a means of representing systems and their incorporated subsystems based on the generic building block, the Configurable Component (CC). Ideas regarding the nature of the CC concept in this section are mainly adopted from Gedell (2009), and presented here in a condensed and sometimes simplified form. (Further reading is recommended for better understanding.) The concept has its origin in the attempt to describe variant-rich and configurable products and therewith, more generally, entire product platforms. The concept is originally designed to allow all functional units and stakeholders, especially engineering, to make use of the product description in their collaboration. Here, the product is seen as a technical system, which the CC concept provides a generic mode of structuring for. The foundation of the CC concept stems largely from systems design and makes use of several basic principles, listed below:

Composition

One CC can represent an entire system. Each subsystem in the system can also be represented by a CC. Further, each subsystem on the next lower level of the hierarchy can be represented by a CC as well, and so on, until the required level of granularity is reached.

Encapsulation and elaboration

The internal structure of a particular system (in other words, the CCs it is composed of) can be concealed (*encapsulation*) or made visible to the interested stakeholder, depending what level of granularity is required (*elaboration*). Thus, the various engineers involved in the development of the product can chose their preferred level of detail when working with the design. In accordance with the principle of composition, information about which subsystems a CC is composed of is incorporated in the CC. However, the subsystems, also represented by CCs, are autonomous.

Parameterization and configurability

The CC concept can be used to describe variants of a system. Parameter values are used to describe which variants of each system, also called configurations, are available or feasible. The parameters are given a bandwidth for this purpose that can accommodate for the varying constitution of each CC, i.e. system. With the CC concept one can therefore build a structure of autonomous systems that configure themselves individually as a response to changes in input parameters.

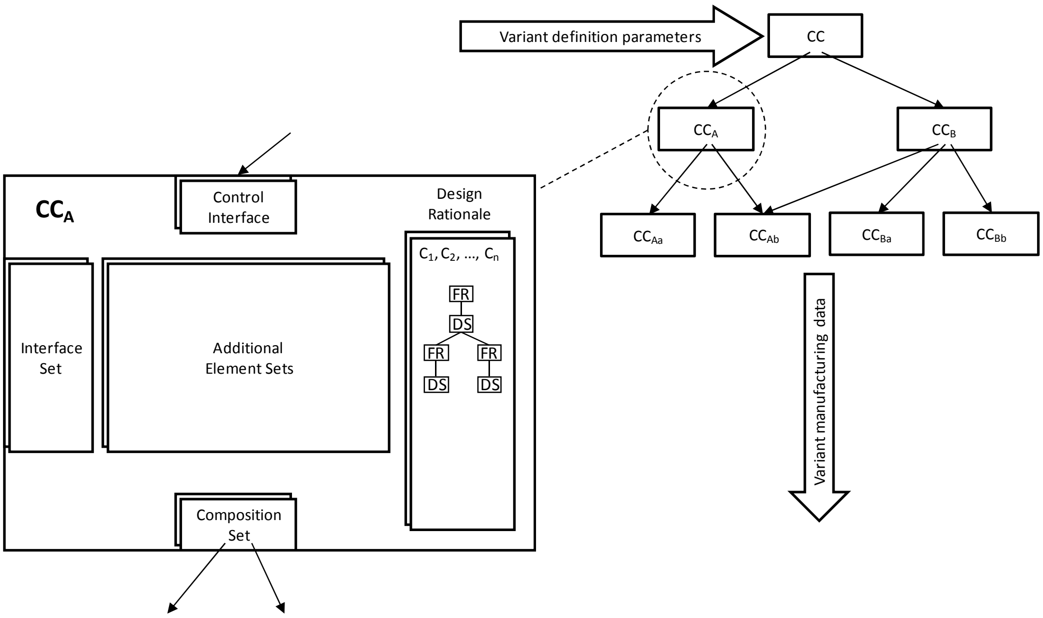

Figure 2. Product platform described by Configurable Components

Design rationale

The reasoning behind selected design solutions, the so-called design rationale, is incorporated in the configurable component. Thus, it is directly connected to the relevant system and the level of abstraction.

Internal elements of the CC

An example of a CC and its internal elements is illustrated in Figure 2. The design rationale is represented by an enhanced function-means tree. The function-means tree includes the system's functional requirements (FR) and their design solutions (DS). Moreover, a set of constraints (C) imposed on the design solutions is included in the tree. All internal elements of the CC, described below, are seen as design solutions. All interfaces for example are the result of a design decision. In other words, they are design solutions.

The control interface allows access to the system parameters, i.e. access for the user or for other CCs. The composition set contains the information defining which other systems, i.e. CCs, are used to further define the considered CC. Both composition set and control interface are used to build a structure based on CCs as the building blocks. Through the interface set, the CC receives input and delivers output on the functional level, answering the question of what function the system fulfills and under which conditions it does so. The CC includes several additional internal elements sets not further explained here the sake of brevity.

The so-called variant definition parameters govern the total system's structure and the configuration of each CC. Together with the available CCs, they define the system platform. Figure 2 illustrates a simplified platform structure using CCs. The illustration only shows the structural relationship between the various systems. The relationships on the functional level are not illustrated. On the premise that manufacturing data can be linked to the system descriptions, i.e. to the CCs, the structure can yield the manufacturing data for each chosen variant.

3.3 Adopting a CC approach to include manufacturing systems and the related processes

The CC concept is a means of representing configurable, technical systems. It was originally defined to represent products. As the manufacturing system, used to produce the product, is a technical system as well, it is to be explored whether the CC concept can be used to describe it, too. The first key issue here is that the related processes of the manufacturing system and their design have to be considered

more thoroughly. In fact, for some engineering tasks in manufacturing, a process view is predominant. This view has to be accommodated by a platform description for the manufacturing system.
Designing configurable systems is an activity for both engineering design and manufacturing. Because of the integrated and concurrent mode of collaboration, it is interesting to explore whether a joint design of product and manufacturing system can be facilitated through an integrated system description. Thus, the second key issue is to integrate the description of the product with the description of the manufacturing system and its related processes. The approach in both cases is to do this based on the Configurable Component concept.
The potential of this integrated systems approach can be contrasted with an ideal scenario. Taking into account the functional organization and the concurrent mode collaboration of engineering design and manufacturing described in Section 2, this scenario can be can depicted as follows:
Two intermediate objectives are achieved while the creation of profitable products is sought. First, engineering design is provided with all necessary means to affect not only the design of the product but also of the manufacturing system and related processes. Second, manufacturing is provided with all necessary means to affect not only the design of the manufacturing system and the related processes but also of the product. Moreover, both objectives are accomplished under two conditions typical of the process of developing products and manufacturing systems. First, neither the product nor the manufacturing system and its related processes are fully defined during the designing process (incomplete) and their description at the given point in time includes contradicting information (inconsistent). Second, a fully concurrent mode of operation, unobstructed collaboration, and the exchange and access of purposeful information are achieved. That includes facilitating teamwork in cross functional teams as well as customer and supplier involvement.

4. Findings

The findings are presented in a structure according to the research questions. The first two sections reflect findings largely detached from the theoretical approach. Meanwhile, section 4.3 includes individual issues and challenges that were identified together with an interpretation of their bearing on the approach.

4.1 Collaboration of engineering design and manufacturing in concurrent development projects

Both companies have prescribed stage-gate processes in place for their product development projects interlinking tasks over function boundaries. While they help to organize the project from a project leader's perspective, they give little detailed information of how collaboration is to be structured on an interpersonal level. Deliverables claimed for each gate are defined by what information has to be included. Standardized measures for quality are not established.
Formalized procedural steps for the collaboration of engineering design and manufacturing are partly represented by the stage-gate processes. Meetings with engineers from different functions and work in cross-functional teams are supplements. However, because not all of the necessary exchange of information is or can be prescribed and scheduled, the interviewees state that they compensate for this lack by contacting other engineers for information according to present need. Though none of the interviewees makes an explicit statement about it, insinuations and the fact that specific colleagues are mentioned by name strongly suggest that this exchange of information depends on personal relationships.
At the aeronautic company, a new organizational unit within manufacturing was recently established. Its purpose is to support product development project from a manufacturing perspective. Some of its engineers are disburdened from executive assignments in manufacturing. Therefore, they can dedicate their entire time to development projects, be it as consulting experts or as project members. Creating direct interpersonal contact over function boundaries, this restructuring can be seen as an approach to facilitating the access to information that affects the manufacturing process. At the automotive company, process and resource planning are not considered until the product is completely documented for production. The manufacturing process is not as complex. Further, one relies to a larger extent on the design engineer's experience. Only new product architecture is tested for its manufacturability, especially if it requires rearrangement of machines.

4.2 Observed approaches to platform questions

Neither company utilizes an outspoken platform strategy. As second-tier suppliers both companies deliver highly customized products fit to narrow specifications from the respective customers. Furthermore, the aeronautic company produces only low volumes of their products (only a maximum of a few hundred units per model). Therefore, a product platform strategy according to the narrow definition, i.e. reusing parts across products, is not in reach or even desirable for either company. It offers only limited opportunity to utilize economy of scale and does not allow the required high degree of customization.

For both companies, the notion of the wider definition of the term platform and the idea of including, the production system, can be recognized as alternatives. The interviewees at both companies this is acknowledge this. At the aeronautic company, several projects concerning the question of what platform strategy to chose and its respective scope were in progress at the time of the interviews. Despite the appeal of a wider definition of the term platform, the aeronautic company also pursues work on defining so-called *design elements*. These are sets of generic physical building blocks common across some product models. When joined together, e.g. by welding, they yield the final physical structure of the product.

The prescribed procedural model of collaboration, i.e. the stage gate process, and the personal relationships present a form of reuse of assets across projects. However, only the former is formalized. Processes and methods for calculations and testing are largely standardized and experience comprehensive reuse across projects. Modeling and simulation methods are an area of extensive development, especially at the aeronautic company. Except for product data management tools, only a few other computer-based means allow an integrated use by all engineering disciplines. At the automotive company an extended materials database allows for quick access by design engineers. It can be seen as the allocation of information from suppliers and purchasing. Attempts have been made to extend the database to include design rules originating in proven manufacturability and prototype testing. The rules are based on a given production process utilizing the given machinery, i.e. a technology and production method platform.

4.3 Unresolved issues and challenges matched with the chosen theoretical approach

In this section, unresolved issues and challenges in the collaboration between engineering design and manufacturing are presented in a short statement marked in bold and by a bullet point. The subsequent text of each paragraph expounds upon the question of how the integrated systems approach based on the CC concept can address the respective issue or challenge stated.

- **The access to information in development projects is dependent on personal relationships.**
  A strong dependency on the individual engineer yields an information exchange process sensible to changes in project teams. An information system based on the CC concept can facilitate the following of a formal information exchange process. This achieves a balance between formal and informal exchange of information and, in turn, facilitates collaboration in concurrent development projects.
- **Understanding other engineers' perspectives is hindered when functional units are spread out geographically.**
  In addition to the dependency on personal relations, harder to maintain if, for example, manufacturing is located at a different site, an imprecise structural description of technical systems can contribute to a lack of understanding. A more precise and integrated description of the product and the production system, including the rationale behind them, can facilitate understanding other engineers' perspectives and decrease the effect of geographical distance. However, it should be noted that there are barriers for achieving shared understanding [Kleinsmann and Valkenburg 2008] which are outside the scope of the this paper.
- **Late feedback on smaller changes results in effort and costs that should be avoided.**
  Large changes do not occur as frequently as smaller ones because they are more easily anticipated and the underlying problems confronted in earlier phases. The challenge of avoiding smaller changes, however, is most likely not to be met by the CC concept. As for all

information systems, maintaining them updated is the key factor. This is a challenge even for an integrated platform approach based on the CC concept.

- **There is a risk of protecting one's own group's interests rather than seeing them in the context of all engineering aspects of the product and manufacturing system.**
  The interrelationship of different systems is presented insufficiently. Consequently, subsystems are optimized without ample regard to others. Integrating a platform description for both the product and manufacturing system can form part of a remedy for this issue. With the ability to work on the required level of granularity while seeing links to other systems, engineers can be supported in balancing their interests. One example is when setting tolerances on the product.
- **It is difficult to prescribe a generic process of collaboration that is fit for all projects.**
  The CC concept aims to describe artifacts and technical processes, i.e. the product and the manufacturing system and its related processes. It is not intended to connect to it a specific procedural model for collaboration. Rather, it should preserve a company's flexibility to choose. However, it can facilitate following the chosen process.
- **A flexible manufacturing strategy is indicated to be able to utilize economy of scale.**
  This challenge is due to the companies' role as second-tier suppliers. That role requires a high variability of products and, especially in the case of the aeronautic company, only allows for small product series. Consequently, a platform strategy for the manufacturing system and its related processes should facilitate reconfigurability of both, to accommodate a large spectrum of products with their individual manufacturing processes. An integrated platform description as expounded in this paper can support a flexible manufacturing strategy. Defining the strategy as such is, however, another challenge.
- **It is difficult to express systems on a suitable level of abstraction.**
  Expressing the aeronautic company's *design elements* in a generic way in order to utilize them in a platform approach is an unresolved challenge. Moreover, assigning requirements to specific *design elements* it has been found intricate. This adds to the challenge of a suitable definition. This particular example stems from the difficulty of expressing systems on the right level of abstraction. The approach based on the CC concept allows system representation on multiple levels. One or several of those can be on the level of function carriers, the so-called *organs* [Hubka and Eder 1992].

The issues and challenges presented are those interpreted as most pressing at the two companies, i.e. in the collaboration between engineering design and manufacturing and with respect to platform approaches. Particularly, those challenges strongly connected to the collaboration process cannot be addressed directly. They are late changes and the difficulty to define a generic process for collaboration. These are outside the scope of what an integrated platform description of the product and the manufacturing system, with its related processes, can achieve.

5. Discussion

The limitations stated above have bearing on the CC concept's capability to help achieve the ideal scenario described above. However, the discussed issues and challenges also draw attention to capabilities that can be helpful as one step *towards* the ideal. Expressing systems information on purposeful levels of granularity and abstraction, while providing information about interconnections of systems, is an advantage. It is one means to support both engineering units discussed here in affecting the design of the product and the manufacturing system. One way, for example, is through helping to balance interests across functional units. Challenges constituted by dependency on personal relationships and hindered understanding were identified in the study. Overcoming them contributes to achieving unobstructed collaboration, exchange and access of purposeful information, and improved teamwork. Customer and supplier involvement on an engineering level can be addressed, where it resembles corporate internal collaboration across distance and mindsets. The question of what purposeful levels of granularity and purposeful information are remains open. Like the question of the correct platform strategy, it is left to the individual company or engineer. Moreover, the goal of managing the incomplete and inconsistent nature of information in development projects is not addressed.

The reliability of the findings should be seen in the light of the explorative nature of the study and the sample size of interviewees. The study was comprised of data collection and analysis conducted in a traceable manner, including full transcription, stepwise data reduction and interpretation, carried out by two researchers, as well as a comparison of individual interviewees' statements to identify parallel answers. Understanding other engineers' perspectives when located apart was seen as a challenge at both companies as both have manufacturing sites abroad. Also, engineers at both companies identified the risk of protecting the group's interest rather than seeing them in context and the difficulty to express systems on a suitable level of abstraction as issues.

Finally, the findings presented in this paper are contextual in two respects. First, the study was carried out at manufacturing companies in the second tier of the supplier chain. The validity of the results, especially the ones related to the first two research questions, is hence limited to the situation of the two respective companies, i.e. second tier suppliers in the manufacturing industry. Second, the chosen approach is based on the CC concept, partly exploring its capabilities. The validity of the concept as such is not tested. Rather, it is postulated. Thus, the results presented regarding the two last research questions are thus valid only to the extent the postulated concept is.

6. Conclusion

This paper has explored a configurable systems approach to integrating platform descriptions for products and production systems. The study supplied data with bearing on the first three research questions, and the data could be used to answer them in part. Moreover, the empirical findings point to a number of issues and challenges. Some of these could be matched with the capabilities of an integrated platform of the product and the manufacturing system based on the CC concept, thus answering the last research question. The reliability and the validity of the findings have been discussed. Significant limitations exist, due mainly to the explorative nature and scope of the study.

Finally, the question of incomplete and inconsistent information in development projects could not be connected to the study data. Moreover, the approach adopted is founded on a systems view. It needs further refinement to account for processes related to the artifacts. These defects should be addressed in further work, preferably connected to a case study that applies the presented approach for a platform description based on a suitable platform strategy.

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