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Examining the Possibilities of Identifying and Modeling Correlations between Product Families and Business Processes

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Abstract
In order for companies to make well founded decisions on the product family makeup, an understanding of the correlation between the complexity of the product family and business processes is required, though it is often not available. This paper investigates the potential of using the Product Variant Master (PVM) modeling technique and Process Flow Charts in combination, to analyze the correlation between complexity in product families and business processes. The approach is based on a visual modeling of the product assortment and the business processes. It is hypothesized that the combined use of the modeling techniques can allow for analysis and communication of the product family and business processes; as well as the connections between the two, with the potential of creating a single combined model. A case from a Danish industrial company is used for the purpose of the investigation. The case shows that it is possible to identify correlations between product complexity and the induced effects in the business processes through the use of product Variant Master and Flow Chart models. Examples are given, and conclusions are drawn concerning the possible usefulness of combining PVM and process flow charts for the purpose of identification and visualization of correlations.

Keywords: Mass customization, product architecture, process architecture, complexity management, platforms

1 Introduction
In the world of today’s competitive business there is an increasing demand for customized products, driving companies to constantly expand their offered product variety, often with the effect of introducing more complexity into the product families [1]. The causal relationship between the complexity of the product family, i.e. structural complexity and component and assembly variance; and the impact of the complexity on the business processes is, therefore, of great interest for projects concerning product development, product redesign, standardization and product configuration. However, although both subjects have been given a great deal of attention, and the interest for the link between them is high, we believe that the results of these efforts have not yet led to a fully practical and useful application in the mentioned project types, partly due to the lack of modeling techniques which can be used by multiple

project stakeholders and participants with different views on the product family. This is problematic because there is a need for:

- Making decisions on changes to the product architecture based on information and data instead of primarily tacit knowledge from experts or other project participants.
- Determining the potential impact on process costs associated with making changes to the product architecture.
- Identifying structure types in product architecture designs that will normally affect the business processes in a positive or negative way.
- Operational modeling of product and process architecture.
- Operational identification of significant process costs induced by product complexity.

The primary reasons for the shortcomings of the previous results are both a singular focus on complexity costs as descriptors of detrimental effects for business processes e.g. sales, engineering, purchasing, production, assembly and installation, and further more that in most cases the modeling of the product family complexity and of the effects on business processes is done separately. The focus on complexity costs also ignores other effects on the business processes e.g. increased lead times, and does not include an assessment of whether or not the complexity is value or non-value adding from a customer perspective. We believe that a broader view of the detrimental effects of product family complexity must be used and included in a single model combining product family modeling and process modeling, and also including the links between product and processes. This would provide project participants with a common model to refer to and a broader base of information, from which a meaningful dialog on the product family makeup can occur and better founded decisions made.

Among the possible suggested models for modeling single products and product families can be mentioned UML based class diagrams [2], Function-Means trees [3], Generic Bill of Materials (GBOM) [4], Product Family Classification Trees (PFCT) [5], FR/DCT scheme [6], Generic Organ Diagram [7], Extended Generic Product Structure (EGPS) [8], Adaptive Generic Product Structure (AGPS) [9] and Product Variant Master (PVM, also sometimes referred to as Product Family Master Plan, PFMP) [7]. While all of these modeling techniques have their strengths and weaknesses with regard to the modeling of products, none of them address the issue of modeling processes and the correlation between products and processes. Among the efforts to link product and process models, two are of particular note. Martin and Ishii [10] propose a promising visual modeling method for showing cost implications of variety by using a modified Product Structure Graph, but this model fails to give a satisfactory representation of the product structure. Zhang and Tseng [11] suggest a method based on UML class diagrams for modeling products and processes and establishing the link between them. While this method suggest a combined model, it is based on a single viewpoint of the product, modeling only the physical instances of the product, and thereby limiting the use of the modeling method for decision making in projects involving participants with different backgrounds. It also limits the use of the product models for the analysis of problems other than complexity costs. According to Andreasen et al. [12] several viewpoints should be considered when modeling a product family, so whereas Zhang and Tseng focus on the physical components, it is our belief that an engineering and customer viewpoint must also be included. The reason for this is, that in order to gain the knowledge and understanding necessary to make the right decisions on the product family architecture, a full view is needed of not only the product family, but also the design dispositions made, the reason they were made and what the effects of them are on business processes and value to the customer.

The correlation between the dispositions made in designing products and the effects on production processes is well described in both various theories for Design for X, such as Design for Manufacture (DFM) or Design for Quality (DFQ) [13] (which also addresses the customer's perception of quality), and the theory of dispositions [14]. Applying the theory of dispositions on other business processes enables a more complete assessment of the product family, and gives a broader foundation for making decisions on the product family. Using a customer, engineering and part view would make it possible to both determine the dispositions made in regards to the product family and why they were made. A customer viewpoint is needed to get an overview of the customer requirements, so as to determine what constitutes value adding and non-value adding complexity seen from a customer perspective. The engineering viewpoint is needed to visualize the functionality, and to link the customer requirements to physical parts. Modeling the physical parts makes it possible to identify component variance and structural complexity e.g. the impact on the production processes of manufacturing multiple variants. Combining this with a model of the production processes should help identify the impact of the dispositions.

This paper thus investigates the possibility of identifying and visualizing the correlations between complexity in products or product families and the effect on business processes with the purpose of making such knowledge easily available and usable in industrial projects. The paper proposes and examines the usefulness of employing the only modeling technique which includes all three views, the "Product Variant Master"-modeling technique (PVM), and process flow charts in combination to determine the operational impact of decisions on the product assortment, as well as the possibility and necessity of developing a combined modeling technique. The modeling technique would ideally also be applicable for purposes other than analysis of the effects of product family complexity, such as product development, product family variance definition and documentation for configuration systems, as is in varying degrees the case of the PVM modeling technique

The research is based on a qualitative case study from a Danish industrial company concerning the development of a new concept for a product architecture. Document analysis, observations and interviews are used to explore possible empirical generalizations concerning correlations between the product assortment and production processes as well as the potential business process implications. While the possibilities for generalization on a single case basis are limited, it should be noted that the intention of the authors is to investigate the possible usefulness of applying the PVM technique and process flow charts in combination to determine if further research is warranted.

The remainder of this paper is structured as follows: In section 2 we define our use of the terms product family complexity and business process effects. Section 3 introduces the modeling techniques of PVM and Process Flow Charts, while section 4 describes how they are applied to the industrial case in combination with certain information and data sources. Section 5 describes the analysis and results of the case, and section 6 discusses the results. The paper ends with section 7 discussing the possibilities for drawing general conclusions from the results and the perspectives for developing a single modeling technique to be an extension of the PVM technique, which would combine product and process modeling and show the links between them.

2 Product family complexity and business process effects

Complexity is an ambiguous term which could be used to refer to many different things depending on the situation of use or the people using it. It could, for example, be used to refer to organizational complexity. To avoid confusion we therefore use the term product family complexity when referring to the complexity of a product family. This definition of complexity may include both the variance and structure of the product family, but does not in this instance relate to the complexity of the technology used to obtain functionality only the variance of the technology. We exclude this view of technological complexity for the reason that we are not seeking to engage in absolute technology assessment, but rather are only interested in technological complexity as it relates to the differences between alternatives in the modeled product family. When evaluating the complexity we note, that it is only in observation of both the consequences of this complexity for the business processes and for customers' value perception that any true assessment of the complexity can be made, since product family complexity in, and of, itself is not necessarily a bad thing or undesirable from a business perspective. At this point we do not seek to determine the exact details of using product family complexity as a metric for assessing a product family, but only wish to determine if it is possible through the use of the suggested modeling techniques. We therefore categorize product family complexity as a binary term in relation to both the effects of product family complexity on business processes and customer's value perception. Product family complexity in this sense is thus described as having either a positive or adverse effect on business processes, or being either value-adding or non-value-adding in relation to customers' value perception.

Complexity Cost is a term often used to describe the main focus of much research into complexity management, and it could, therefore, be thought to be appropriate for our purpose of assessing a product family. However as stated, when one considers the dual effects of product family complexity on both business processes and customers' value perception, the analysis of costs alone is not sufficient. The reason is that while attention to costs may be important for business performance, a full understanding of the consequences of product family complexity on business performance relies on more than simply cost minimization. The impact of product family complexity on business processes must, therefore, rely on an analysis of the effects on business processes, which includes among other things costs, lead time, quality, on-time delivery, stock etc. This also serves to ease the task of relating the effects of product family complexity on the business processes to customer requirements or demands, the reason being that certain effects, e.g. lead time or quality, are more directly relatable to customer requirements and can be difficult to assign a cost value.

3 Modeling products and processes

With the perspective in mind that the modeling techniques used for product and process modeling should be used in combination and potentially combined into a single modeling technique, it might perhaps be advantageous to employ modeling techniques which are based on similar or related modeling principles. It is among other things with this in mind that the modeling techniques were chosen. The following sections present the two modeling techniques.

3.1. The Product Variant Master

The Product Variant Master modeling technique was chosen as the basis for the product model due to its proven usefulness in multiple industrial cases [15][16][17], which in large part is due to its capability of modeling three crucial viewpoints, the importance of which is described by Andreasen et al. [12] ("Multiple structures" page 33) in a manner that allows for easy intra-organizational communication. The modeling formalism also has as one of its main strengths, the clear representation of commonality and variance of the product assortment in two separate structures, making it easier to identify structural complexity by noting the complexity of the product architecture and the variance of components and assemblies. The PVM modeling technique as described in Harlou [10] has its basis in object oriented modeling. In the PVM, Aggregation structures from object oriented modeling (denoted Part-of) represent the structure of the product family and the subsystems, while generalization/specialization structures (denoted Kind-of) represent the variance of the sub-systems and components (see figure 1). The PVM is divided into three sections describing the three viewpoints: Customer view, Engineering view and Part view, which can be described as follows [7][18]:

- Customer view: Describes the product family from a customer's point of view. Contains the aspects of the product family that are relevant for the customer, e.g. performance and interfaces to the environment
- Engineering view: Describes the product from an engineering point of view, and should describe how the product functions. Contains the functional units and solution principles contained in the product family
- Part view: Describes the physical entities of the product family. Contains the physical components to be dealt with in production, purchasing, logistics etc.

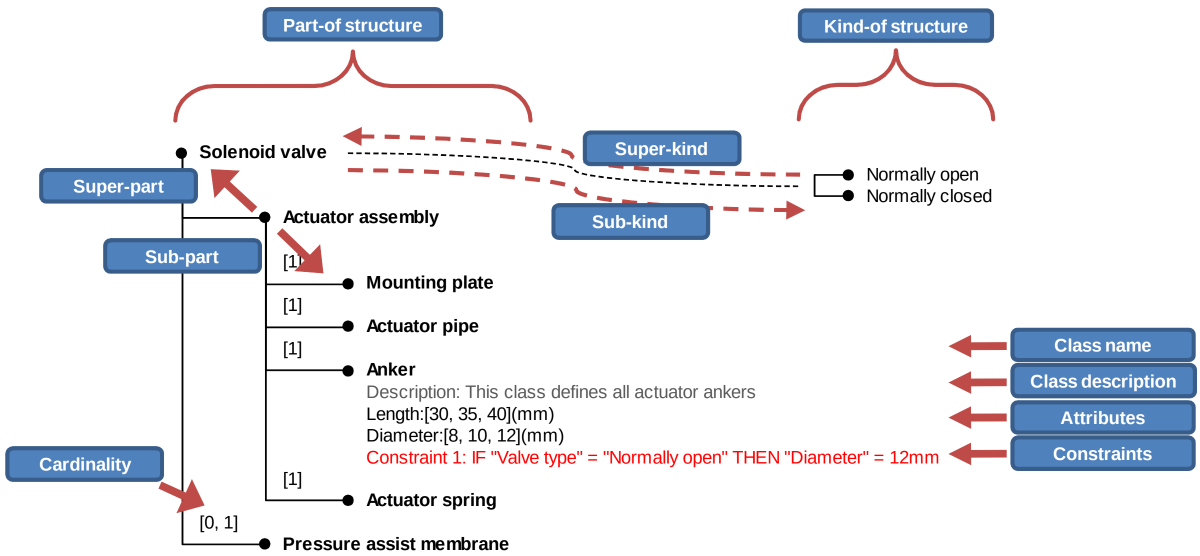

Figure 1. Example of PVM notation

Links between objects in the three views make it possible to follow the connection between customer requirements, the realization of the requirements through the function of the product and the physical realization of the functional units. The links can therefore be used to assess the structure and variance of the product architecture by revealing unnecessary complexity. Unlike many of the modeling techniques mentioned in the introduction, the PVM also has the advantage of utilizing a hieratical notation that is commonly used in other contexts, and it is therefore often easily understood by project participants without a technical or engineering background. This makes it ideal for communication across company functions and makes it a good starting point for analysis and discussion of a product family. The modeling technique also already addresses the production process indirectly by directly modeling the elements that are to be produced, as objects that are changed by the production processes.

3.2. Business process flowcharts

For modeling of the business processes it is suggested to use flowcharts, based on e.g. Activity Diagrams [19] or Business Process Modeling Notation (BPMN)[20] from UML to name a few. By using either of these modeling techniques, the product family model and process model would share a background in object oriented modeling, making it easier to link the product and process models. Elements of technical process modeling for production processes based on the theory of technical systems [21] could also be useful. The flowcharts are constructed of a set of shapes representing activities and decisions connected by arrows signifying flows. The modeling can be made on different levels of detail, and it is suggested to let the level of detail reflect the detailing of the PVM. For the flowchart models of the production processes, the process steps describe the operations made on physical entities, i.e. the physical entities modeled in the Part View of the PVM. As such, objects are shared between PVM and flowcharts, and a direct link can be made in this manner. For flowcharts describing other business processes not directly related to production the link is as of yet not clear, and it is uncertain if such a direct link can be made, or if an intermediate model is necessary. The flowcharts are supported by a separate collection of information and data concerning performance of the processes in the flowcharts. These should preferably be based on extracts from company computer systems, direct measurements and observation, though interviews with domain experts are likely to also be a source.

4 Empirical investigation

A case study was carried out in the spring of 2009 in collaboration with a Danish industrial company manufacturing customized products for the agricultural industry. The study was done in connection to a project concerning the development of a new common product architecture concept for three product families in the early stages of a redesign project making it a good example of a project, where obtaining in-depth knowledge of the products and processes was necessary for the purpose of making well-founded decisions on the nature of the new product architecture. The three families (A, B and C) were all part of the same commercial product range and had a great similarity of function, features and technology, and also shared some components and modules though they were developed and launched at different times (the oldest one more than 30 years ago). At the time of their launch they could be divided physically and functionally along a small, medium or large distinction. This distinction is no longer as clear as all three product families have seen great increases in their variety as a consequence of changing customer demands. The increase in offered variety was to a large extent not always achieved through reuse of solutions and modularization, nor followed by continuous assessment of the product range with the purpose of reducing complexity. The project was, therefore, the first comprehensive analysis and assessment of the product families in a long time, resulting in a sufficient base for analyzing complexity. Particularly the medium (B) and large (C) product families, now for the most part offer the same functionality, features and capacity. For the purpose of this investigation it is therefore reasonable to treat the two families as variants of a single product family, which forms the base of our analysis. This is supported by the definition of a product family defined by Meyer and Lehnerd [22] as “A product family is a set of individual products that share common technology and address a related set of market applications”.

The project relied on an analysis of the product, production and market as the basis for decision making, with a PVM used to model the product families in a common model and high level flow charts (primarily of assembly processes) used to model the production process. Information regarding the company’s resource consumption and product complexity consequences was gathered through interviews with production managers, direct observation of the production system and cost comparison of certain key assemblies. In this specific case we primarily focused on effects on the production processes describing costs and lead times for the assembly processes. Other business processes could also have been considered, but for the purposes of this investigation the chosen processes were considered sufficient.

Verification of the PVM was done with the help of domain experts from the company. The intent was to identify the main assemblies and components which determined the offered market variety and had the largest influence on the production processes. The PVM was based on BOMs, online spare parts catalogue, product manuals, company website and interviews with domain experts including engineering, product management, production and sales personnel, and it reflects the two different sales forms of the company: fully assembled products and semi-assembled kits. Process flow charts on a fairly high level were made for the main assembly process, showing only the major steps in the processes and certain sub-processes (see example in figure 2). The basis of the charts was direct observation of the production processes and interviews with production managers and workers in the production. Data and information collection was partly based on Value Stream Mapping [23].

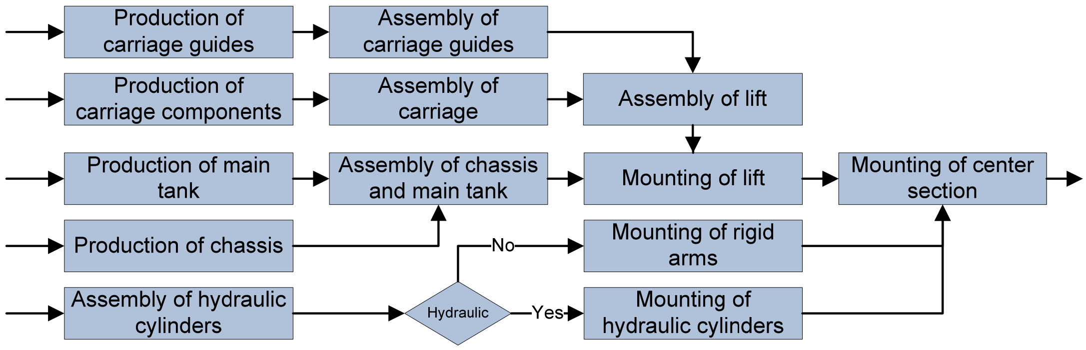

Figure 2. Small section of the assembly flow chart for product family C

4.1. Guidelines for analysis of the models

The PVM was discussed in review sessions with domain experts, and conclusions were drawn on the structure and variance of the product families. Differences in architecture and component or subassembly/module variance were noted as signifying a complexity in the product families. Among the types of complexities identified were:

- Differences in the generic structure of the products, i.e. the product architectures
- The assembly level wherein structural differences were found
- No. of component or subassembly variants
- Assembly level for which component or subassembly variants occurred
- Degree of variance for functional solutions

To the extent possible the identified complexities were associated with a particular subassembly or component. These were then used to identify the correlation between the product and process models by observing the components' or subassemblies' interaction with the production system (as illustrated by the process flows) by tracking their flow through the production processes. It was expected to see that differences in architectures would result in different process flows, differences in the resources used and in the performance of the processes. By analyzing each process, the effects of the complexity should then be possible to identify. Detailed measurements of process effects were not carried out since the goal was not to achieve a detailed description and metric for the correlation between complexity and costs, but rather to determine that a correlation could be identified. The possibility of detailing such correlations should be the subject of another study.

5 Results

The product families offered several customization options, which should ideally have been achieved through a high degree of modularization and use of common interfaces, but although there were examples of such a modular mindset within parts of each of the product families, cross family component/module sharing was limited, as evidenced by the PVM and supplementary BOM statistics. The consequence of this lack of modularity and common product architecture was significant differences in assembly flows and thus long lead times and high costs, as seen by following components and subassemblies in the production. Recommendations were made to bring about a greater commonality in the structure of the reduction of the component and assembly variants fulfilling similar or identical functions. Below are presented some examples of correlations found when tracing the effects on time and cost attributed to components or modules identified as increasing the product family complexity:

5.1. Degree of variance for functional solutions

Variance was identified in the functional solutions for a lift system with a significant difference in component numbers. The result was the addition of sub-processes in the assembly flows due to the different functional structures. It was found that the variance in functional solutions was especially crucial to the addition of processes and possible sources of increased costs. This lead to a significant impact on the assembly time for final assembly (see table 2)

Table 1. Average assembly time for final assembly

	Product family B	Product family C
Final assembly time	12 hours	24 hours

As a result of the identified time differences, and due to increased customer requirements for the lift system, it was decided to leverage the superior assembly performance of product family B to create a new variant of the lift system in the new product architecture that could deliver the slightly better functionality of the lift system in product family C. The new system was thus a combination of the two systems based on the best traits of the two old systems.

5.2. Differences in the generic structure of the products, i.e. the product architectures

Chassis capable of supporting the same weight and with the same functionality were present in different variants, resulting in different production processes that carried different costs and production times (se cost example in table 2).

Table 2. Normalized standard cost of chassis in example variant

	Material cost	Salary cost	Total
Product family B	0.53	0.19	0.72
Product family C	0.52	0.48	1

As a consequence of the identified differences in standard cost for the chassis variants, it was decided to base the chassis in the new architecture on the chassis in product family B, while also creating a new chassis for a higher capacity machine. The new chassis were expected to have production costs slightly above the current cost of product family B, mainly due to higher material costs.

6 Discussion of results

Linking the process flow charts to the PVM, as shown in the examples, made it possible to determine whether or not the product family complexity had positive or adverse effects on the business processes. Through a comparison of this knowledge with a categorization of the complexity as either value-adding or non-value-adding in relation to customers' value perception, a more sound foundation for making decisions on the structure and content of the product family was achieved, thereby showing the usefulness of addressing this link between product family and business processes. The PVM helped to identify where in the process flows to focus attention and what to look for by providing an analysis of the product that could identify possible complexities that might induce undesirable costs in the production processes. It also made it possible to evaluate the consequences for the functionality of the product and the impact it would have on customers when eliminating product complexities based on the cost findings. In this way it was possible to identify how the product architecture should be changed based on more objective observations and data rather than the tacit knowledge of project participants. In general the flowcharts helped to identify among other things:

- No. of different process types
- No. of different flows including unnecessary/additional processes
- Processes where assembly time might be negatively affected by variance
- No. of different tools or fixture used in the processes

Thus, the process flow charts became guidelines for further analysis of the processes, highlighting the consequences of product family complexities and acting as guides for where to carry out process measurements and further in-depth investigations. Using and linking process flowcharts to the PVM made it possible to compare the different possible process flows in the assembly stage and connect them to variants in the product family.

7 Conclusions and further research

The case indicates that applying the PVM and process flow charts in combination, could be an effective means of analyzing product families with the purpose of reducing complexity. The process flow charts add information regarding business processes which is not directly available in the PVM, and the PVM adds information about the product which is missing in process flow charts. The combination of the two modeling techniques thus make it possible to say something about both the product and the processes, not just about the consequences for business processes as a result of product family complexity, but also the consequences for the functionality and offered market variance of seeking to eliminate or reduce costs in the business processes. There is, however, still a need to develop a coherent model incorporating these two modeling techniques, and set up guidelines for how to read the models. The process flow charts must also be expanded with modeling techniques and metrics for modeling the effects associated with the product complexity, since the flow charts are only capable of showing the flows. Furthermore, there is a need to set up more formal guidelines for identifying and describing the product complexity in the PVM, as well as guidelines for how to build the structure in the PVM and determining the detail level for modeling a product. The identification of links between the product components and business processes which was mostly done through tracking of the components and assemblies, and the method for visualizing the links and performance implications in business processes must also be further examined.

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