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ON THE DEVELOPMENT OF PRODUCT FAMILY ARCHITECTURES; COMPARISON OF BUSINESS-ORIENTED AND FUNCTION-BASED PRODUCT STRUCTURING

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ABSTRACT
In the mainstream of textbooks considering the Product Design issues, the functional structure of the product has been presented as the primary basis for defining the modular structure. However in current research streams there exists approaches which emphasize the requirements originating from business- or production environment as a starting point for a design process. In this paper we examine eight industrial cases using functional and non-functional design approach. As a result, we find out that analysis process other than function-based gives better results in five cases out of eight.

On the basis of this observation material, our conclusion is that the functional structure is not an essential starting point for forming a modular architecture. Functional structure is related to the transformation implemented by the technical solution and therefore is a dominant element *in the area of product structuring*. In variant modular product, the modularity of the product is no longer only related to the transformation implemented by the technical system. It now seems obvious, that designing a product and designing a variant structure of a product family are totally different tasks and thus require different methods.

Keywords: Modular Product Structures, Design Processes, Product Families

1 INTRODUCTION
In a number of previous studies, the functional structure of the product has been presented as the primary basis for the modular structure. However, as shown in this research, the approach has an alarming failure rate in real-life industrial cases. A wide take of prevailing design theories is analyzed to mirror the approach taken by this paper followed by examination of several industrial cases to tie the research subject into real-world situations. The eight industrial examples presented here prove that functionality is not always relevant in the design of the modular division of a product family from the business environment viewpoint. It is shown that there is less justification than it is generally thought for prioritizing the functional structure over the other motivations for modular product structure.

Function-based approach may yield results in developing modular structures but often it fails by emphasizing issues that are eventually not relevant from real-world-goals perspective. It seems that the suitability of the function-based approach is good for designing solution in a single product development case, but functional division is not very interesting on the product family level. According to this observation, we conclude that in developing product family architectures, the primary motivations should be lined with the goals arising from business environment and the functional structure of the product should not be used as a primary motivation, but as a boundary restriction.

2 FUNCTION-BASED APPROACH AS MAINSTREAM DESIGN METHOD
The function-based approach is well represented in the design textbooks and even in standards. The best known function-based approach is the German school of Design (eg. [24] [30] systematic design). Starting point for the presented systematical design process is the abstraction of the task formulation. The goal is to break free form existing solutions, to be able to openly search for the optimal solution

for the situation at hand on the basis of defining general functions. This systematical design process is not a law of nature. Design may also proceed in other manners, for example using the Altschuller approach [e.g. 2]. The systematical design process is, however, a generally accepted procedure within Design Science, and the methodologies developed within the field are created for this particular process. Neither VDI 2221 standard nor Pahl,&Beitz do not regard the design of modular architecture a specific problem although the VDI 2221 standard even mentions the word ”modular design”.

In their work, Karl Ulrich and Karen Tung aim to define *modularity* as a system feature. For example, in their article “*Fundamentals of Product Modularity*”, published in 1991, they remain neutral in the issue of what modules are like, but instead define that modularity is a relative product property [28]. According to Ulrich, modularity is a relative property of the product which increases if the functional structure and the physical structure become similar and no dependencies exist between the various elements unrelated to the (main) function.

In the United States, two well-known textbooks of product development are ”Product Design and Development” [29] by Karl Ulrich and Steven Eppinger, and ”Product Design” by Kevin Otto and Kristin Wood [23]. The former defines modular architecture as having two properties; part elements implement one or a few functional elements in their entirety and interactions between part elements are generally fundamental to the primary functions of the product. The part of the book by Otto & Wood on the design of modularity, pages 357-409, is written in co-operation with on Robert Stone, and the modularity methodology carrying his name is utilized in the book. The book also follows the method of systematical design (research conducted by Pahl & Beitz is mentioned as one of the great advances in Design Science) and refers to the research of Ulrich and Tung. Otto & Wood define that there exist two types of product architecture: integral and modular. Integral (according to Cutherell) is a product *”... where all of the sub-functions map to single or very small number of physical elements”*.

Otto and Wood suggest two design methods for modularity: the clustering of function-based elements and the”Advanced Functional Method”. The latter method is based on analyzing the functional structure in relation to three heuristics. The first heuristics is to discover the Dominant Flows in the functional structure which come from the outside of the product and return to the outside. The other heuristics is to discover the ”branching flows” or the functional groups that branch off the main flows. The third method is to look for ”transformation-transmission modules” in which the energy or the material changes form.

3 DESIGN MANAGEMENT RESEARCH ON THE REQUIREMENTS ORIGINATING FROM BUSINESS OR PRODUCTION ENVIRONMENT

The success of a modular product is largely dependent on product-external factors. In a technical/economical system, a modular product has a number of other dimensions besides functionality and internal architecture. The modularity of a product does not in itself suffice to make it suitable for a business or a production environment. Even very limited modularity may be sufficient if it meets the requirements set by the business environment of the product. This might lead to a conclusion that modularity, often considered absolute and exactly defined, changes in a real business environment into relative and goal-dependent. This has been addressed by a number of researchers.

Alternative approaches exist in the field of product structure research. One of these is the *Modular function deployment* (MFD) approach by Gunnar Erixon. In his dissertation, [8] Erixon defines modularity without the aspect of functionality: “*Modularisation is a decomposition of a product into building blocks (modules) with specified interfaces, driven by company-specific reasons”*

Carliss Baldwin and Kim Clark have conducted much-quoted research in the field of modularity. The research material comes from the US computer and computer accessory manufacturing industry. The examination period in their research stretched from the post-WWII era till today. To support their views, they are able to present well-known business cases from the recent history of information technology in the United States. Their ideas on modularity are presented in the 400-page book ”Design Rules – The Power of Modularity” [4].

Baldwin and Clark suggest that modularity will become the dominant norm in industrial operations. They see it as a development trend in industrial production. [3] According to Baldwin and Clark, when operating in a Modular Environment, the key issue is to form the product development organization according to the modular structure.

Baldwin and Clark approach to modularity applies the perspective of business management, whereas this research focuses of product design. The differences in the research material also lead to, for example, a very different terminology. B&C use the term ”architecture” mostly in the historical sample cases, such as in the case of the development of the world's first bus-modular computer [Baldwin & Clark 2000: IBM *Standard Modular System* development work 1957-1958, pages 163-165]. They talk of *Design Rules* that in their method that contain the compatibility data generally considered as the architecture. Baldwin and Clark examine modularity in a networked business environment, in which case the forming of the module structure as the dominant design emerges as one of the key issues. On the basis of this, B&C consider that a modular structure can only be created on the application area via evolution. This is probably true in a networked business environment.

In their research, Cantamessa and Rafele highlight the conflict between the general definitions of modularity (e.g. Ulrich) and the industrial practices [6]. Their application area is the car industry in which the situation is clearly visible. They refer to earlier research [5] and argue that alternative approaches exist for applying modularity. They proceed to question the status of functionality in the development of modularity: ”*The relevance of these alternative viewpoints suggests that, in product development, functionality is not the only aspect that should be taken into account when defining product architecture”* They present a model of the product development process in which the modular architecture is not formed by using the functional division as the main criterion. The starting point is the bill-of-materials of the product, which are then grouped into modules. One criterion that deserves a separate mention is the charting of a technological roadmap that indicates the need for change in the modular structure (cf. the motivations for modularity as Erixon's ”technology push”). In addition to the development of technology, a case-specific reason hierarchy is formed as the basis for developing the modular architecture.

Nils Kohlhase and Herbert Birkhofer suggested already in 1996 that the modular structure could be created on the basis of computer-based optimization [13]. According to the development model of general modular systems presented by them, the design of modular systems is process-oriented until the concept phase. After this, the design of the modules proceeds as product-based, that is, according to the process of systematical design. This research does not completely separate itself from the function-based approach, as no particular initial method of defining the modular system is selected (the alternatives seem to be the assembly-based or the function-based method, both generally known). Instead, in the optimization of the modular structure the criteria arises from the business environment and the customer requirements (or, according to the terminology used in this research, from the value chains). The difference in the task of designing a modular structure is compared to product design, and it is taken as a separate process to be carried out simultaneously with product design.

A particular type of modularity research consists of the methods of platform research in which optimal size ranges and dimensions are sought in the product range to be able to cover the technical requirements and the customer requirements with a minimal number of variants. These methods can in principle support new product design, even though the sample cases usually analyze an existing product range. Research of this type usually leads via standardization to a component platform.

PPCEM (Product Platform Concept Exploration Method) is a method in which the correct dimensions are sought and defined for the variant product family via calculatory means. [26] The most interesting tool of this method is the *market segmentation grid* [originally 21]. It defines that product variation can be achieved in two ways: via *parametric* and *configurational* variation. The latter term cannot be explained by its semantic meaning - we are talking about variation that affects the generic assembly structure via changing parts in the product. In a market segmentation grid, the market segments are drawn vertically on the x axis, and the power, size, and value classes horizontally on the Y axis. Thus we can state that vertical variation can primarily be controlled by using parameters, while horizontal variation usually requires configurational changes.

The ”Design for variety” methodology by Mark Valeton Martin and Kosuke Ishii aims at creating a standardized product architecture with a modularity. The aim is to create a product platform in which future changes and modifications are considered [19, 20]. This method also starts from the charting of the market situation and the product strategy of the company. The weights and dependencies from the product elements of the various requirements are defined with the well-known Quality Function Deployment method (QFD, see e.g. [7]). After this, the focus is shifted to the expected changes in the customer requirements. After this, the design values are evaluated and in the next phase normalized, so that the change in the various values can be proportioned. These are used to create the *Generational Variety Index* GVI which estimates the scope of the effect of the external pressures for change on the product element. Defining the pressures for change shows (according to the developers of the method) which parts of the product ought to be formed as modules and which can be manufactured via standardization.

4 ANALYSING EIGHT INDUSTRIAL CASES

The sample material for this research has been collected from research work since 1997. The authors have been working with the companies in these development cases (except Scania and Transtech analyses which are based on the existing material and Ponsse case on interviews). Due the limitation of the space available cases are summarized. The full descriptions of the cases can be found in reference [16].

The industrial examples in this research are

1. A tunnel drilling rig from Sandvik-Tamrock Corp
2. A truck from Scania Corp.
3. A diesel locomotive from Transtech Corp
4. A passenger ship from Aker Yards (now CSX Europe)
5. A safe box from Kaso Oy
6. A machine tool from Fastems Oy
7. An ambulance from Profile Oy
8. A forestry machine from Ponsse Oy

The questions interesting to us are: is it possible to define function-based modular structure in this case and is this structure relevant to business goals and could some non-functional based tool yield better results? The second question forces us to choose a non-functional design tool. Such tools do exists as seen in the chapter three. However in this research we would like introduce one more approach: The Company Strategic Landscape. It is shortly described in the following chapter.

4.1 Company Strategic Landscape

The framework model – Company Strategic Landscape (CSL) [11] – defines the elements related to the product development operations and the production of the company. The figure below shows which relations between these elements are dominant and thus important. In research aiming at the development of operations, measures must be directed to the management of the guiding relations, as these will guide the entity in reality. Elements related to funding (investment capitals etc.) are not presented in the figure 1 next page.

The CSL-framework model describes the key issue entities for the structuring of the product and the contents of the relations between them. The product structure itself is in the top left corner. In this figure, the ”structure” of the product does not refer to the mere assembly structure and a list of parts, as a product assembled of the same parts may be divided differently from the viewpoint of product structure management. The structuring of the product is guided by a value chain (the structuring of the value chain) in which the product must operate. On the other hand, the properties of the product structure also enable and limit the number of the possible value chains. The value chains, in turn, are determined according to the business goals (the structuring of the strategy).

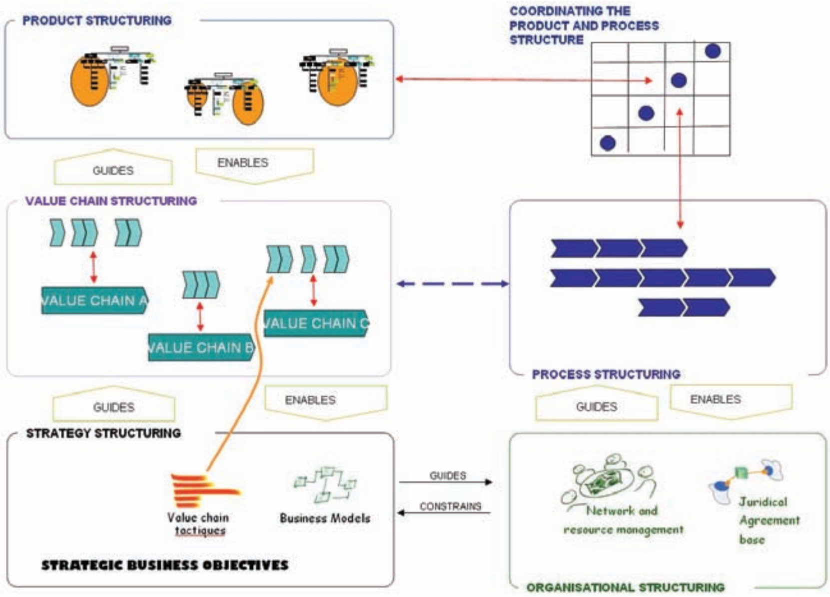

Figure 1. In the Company Strategic Landscape framework, business operations are seen as an entity.

The sales, design, and production processes of the products and services to be delivered are shown in the middle on the right-hand side. In their background, we can see the structure of the internal resources and the network (the structuring of the organization) and the selected methods (operative interfaces). The structuring of the organization and the business goals exist in a reciprocal guiding and limiting relation to each other.

The key idea in CSL-framework model is the relation between the internal structure of the product and the delivery process. In principle, the product structure and the delivery process can be selected separately and are usually examined one at a time by approving the other as a static background data. When optimizing the operations, these two are no longer seen as separate, but they must be synchronized. The points in the table on the top right corner indicate the product structure/delivery method pairs that are ”good points” or combinations in which the operations are carried out rationally according to the *selected goal*. In the figure, the points are located on the diagonal line merely as an example. The points do not necessarily form an unambiguous vector – good points are not necessarily found at all. We must note, however, that the ability of the various delivery methods to support the set *goals* differs drastically. Let us interpret the figure: a certain design process defines the product structure that supports set goals. The product structure, in turn, only enables certain value chains that only correspond to certain business goals.

4.2 Tunnel drilling rig case

The first industrial case presented is research related to the modularity of a tunnel drilling rig was conducted at Sandvik-Tamrock in Tampere during 1997-99. During the project, we examined a number of Tamrock product families, but mostly worked with the Jumbo tunnel drilling rigs. A tunnel drilling rig is a mobile machine on rubber wheels the purpose of which is to drill more or less horizontal holes on the back wall of the tunnel as locations for the bursting charge.

There exists a great deal of variation in a tunnel drilling rig even within the basic model line. All machines are order-based, and the production numbers of individual models were not big. The delivery time was often critical in devices to be delivered to construction sites. In these, the way of working involved several contractors submitting an offer for the contract. The contractor invites tenders for the tunnel drilling rig from selected suppliers as the basis of his pricing. An order on the machine is placed only if the contractor wins the contract. At this point, the actual machine delivery is urgent, as the work must be started. In addition, the site manager decides some of the requirements for the machines; site managers are often only hired after the contract is won, which means that the original machine offer will have to be made on an estimate. For this reason, the remaining alternatives for Sandvik-Tamrock were project deliveries or systematical product configuration. Of these, the selected strategy was the latter one, and the purpose of the research was to discover the most economical product structures for this particular method.

In the research, we started with applying functional modularity. For this reason, a functional structure was drawn of the tunnel drilling rig that described the implementation used at the time. The diagram was used to recognize functional modules. However, the work did not yield results. The modules to be outlined in the diagram could not be implemented in practice in the assembly structure, and they did not yield a necessary level of variation. After this, we proceeded with the work by moving on to matrix methods. The clustering method did bring out the same result. There were no evident functional modules in this product family.

Inspired by the article written by Kos Ishii [10], a new analysis method was developed. It has later been called the *Late Point Differentiation analysis*. [14, 15] The initial data of the analysis are:

1. The relations between the sales selections and the modules
2. The order of the time sequence in production and assembly
3. The order of the sales selections (confirmation)

On these basic data, an *Inter-Domain* matrix is created, in which an analysis of the *alignment* type is performed (according to [18]). The sales selections are on horizontal rows in their order of confirmation. The vertical columns of the matrix show the modules in the order of which they are executed in the manufacturing or assembly. The effect of the sales selections on the modules is marked on the matrix. After this, a diagonal line is drawn from the top left corner to the bottom right corner, which represents the progress in the manufacturing of the product. The location and the form of the diagonal line are determined by the time sequence of production. The tool was capable in analyzing whether proposed solution was viable or not. As a whole, the development process was successful and the tunnel drilling rig family did succeed in the market.

Applying the Company Strategic Landscape framework model would have forced us to evaluate the requirements arising from the value chains (that is, the special phasing of the order and delivery chain) and the matching of the product structure and the delivery process already in the beginning. Late Point Differentiation was used as a tool to seek the synchronization point of the product and process structure. The research conducted solely in the product structuring domain did not yield results, as the functional structure was not a dominant qualifier for the product structure in this case. This had been visible right from the start if CSl would have been used as a starting point of the development process.

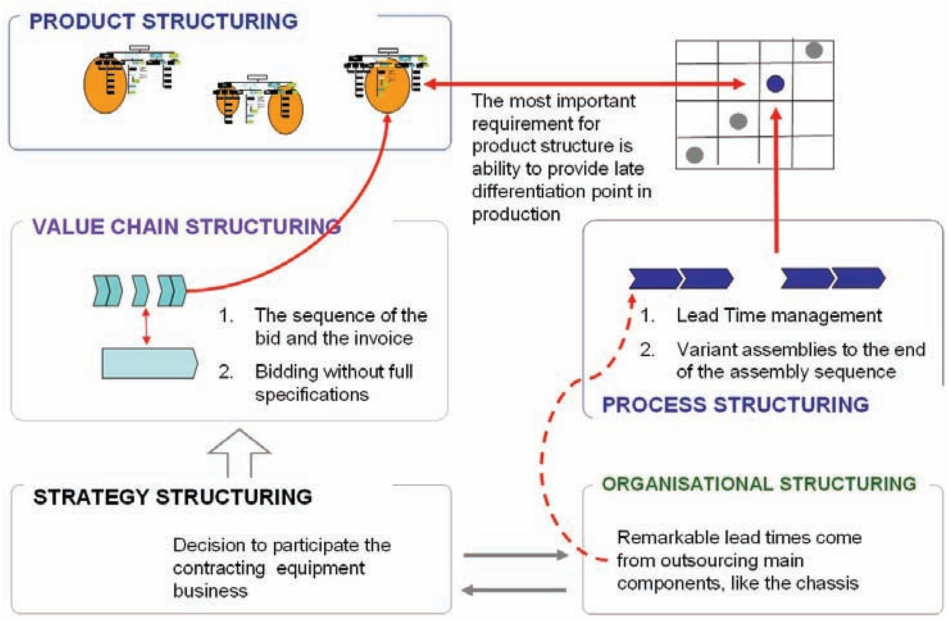

Figure 2. The CSL-framework model about the development of the product structure in the case of a tunnel drilling rig. The key challenge was not to divide the functionalities into modules, as the functionalities were most changed in their parameters. The key issue was to design product structure enabling such variation at the end of the delivery process which was required due to the nature of the value chain.

4.3 Summary of the Scania truck case

In the case of Scania, the conversion of standardized and rationalized product range into a fully configurable modular product line takes place when shifting from the model series three to the model series four in 1996. The key decision was to create four product families which were formed around the frame of the truck. In order to find out, whether the key elements of the product new modular architecture could be found with functional approach, a test was made. A small group of university teachers and Ph.D students were asked to draw out a functional structure of the truck. None of the participants made the structure such in a way, that key elements were visible. After this we made reverse engineering to find out, what kind of functional model could be found behind the structure chosen by Scania. One plausible outcome was, that functional model could be done according the guidelines of The Theory of Domains [see eg. 1]. Actually the key elements of the product structuring decisions could be seen clearly in the domain of transformations (according [9]). According this knowledge it was possible to form the suitable function structures. As a conclusion we see, that it would have been possible to recognize the frame as a key element in different use cases by using functional analysis, but it would require more theoretical approach than normally is used. In the CSL-framework this outcome is more evident although this approach is able only to show requirements, not the solution.

4.4 Summary of the Transtech diesel locomotive case

Our diesel locomotive example hails from the mid-1980s' Finland, when the Transtech rolling stock factory in Tampere developed a new diesel locomotive for the National Railways. Invitations for tender for the new, general-purpose diesel locomotive were sent in 1982. The actual agreement for purchase was made on 16 November, 1983. At that time, the agreement covered the delivery of two prototype locomotives to be delivered in 1985-86 and of a series of 21 locomotives to be delivered in 1987-1991 [25]. These 23 locomotives were supposed to be the first batch to be manufactured in a series of a new successful product. Unfortunately the product was no success. There were no following orders.

This locomotive was undoubtedly a modular product. Modularity in the locomotive is assembly-based, but we can also see clear function-based modular divisions in its design. There were critical problems however, which partially could be traced back to modularization decisions. The commonality with future models was mere assumption at the time the design work was started – the product family could not have been developed any further on their basis. The existing and known variations in the form of different engines could not be managed at all via means of modularity. One reason for this is probably the strict total weight limit which had lead to case-optimized solutions. The new technology proved to be one source of the problems related to operational reliability. The implemented modularity was not able to minimize this problem.

It is obvious that no clear goals were set for modularity. The CSL-analysis would not have supported applying the modularity according functional division as it was done. A conclusion of the analysis is that in a prototype series of a weight-critical product containing untested high technology, applying modularity to the entire product is not a solution required by the business environment. Perhaps modularity was a wrong choice considering the maturity level of the product.

4.5 Summary of the Aker Yards passenger ship case

In 2004-2006 there was a project for ”Improving the efficiency of a ship delivery via means of modularity and flexible standardization”. The purpose of the research was to discover on which bases the division into modules ought to be performed in a ship delivery in the Finnish marine industry cluster. In the project, we aimed to present such a product structure and a related method of operation that the first prototype ship in its series could be delivered for the price of a similar, so-called serial ship delivered earlier. To enable this, the level of design reuse in similar-design serial ships ought to be reached in the prototype ship.

The benefits of the functional division were apparent: elements of the similar (or even identical) type are arranged in the same delivery entity, the integration phase of systems such as pipelines is facilitated or eliminated, and reuse is facilitated as the *function carrier* (or organ) level becomes visible in the design documentation. Unfortunately also evident was that in such a big project delivery, it was not possible to arrange the work division of subcontracting companies according the functional structure. The work division in the project delivery was found the most critical in the product structuring and this division has to be made according the building/delivery process of the ship and abilities of the subcontracting companies. In addition, a single product model was not enough, because there were four different building/delivery processes. It was found that certain building/delivery processes and product structures formed a matching pair where the operation was very efficient. [17]

In this case, drawing a CSL-framework model would have lead to the charting of the value chains and the processes (which were done by other means). Drawn in a framework model, however, they clearly show that there exist good product structure and delivery process pairs. Acknowledging this information at the beginning of the research project would have directed the research in the direction of the results.

4.6 Summary of the Kaso safe box case

During this project, we examined the product families of burglary-safe boxes and fire-safe boxes. The aim was to discover the opportunities for shifting from the production of standard models into the production of configurable products. In principle, it would have been possible to create a modular and configurable safe box. We can even claim that the modular structure is function-based if the functions of the safe box are the ability to take in items and the ability to provide a safe place for them. In this case, the size range is related to the first function and the security classification to the second. However, here we must pose the reservation that the design-related challenges were not solved during the research.

Even though it seemed possible to achieve modularity when examining the product, the case was no longer so when examining the production arrangements: big changes and investments would have been necessary. In addition, from the viewpoint of business operations and value chains, the benefits to be gained with modularity remained alarmingly thin (this was detected in customer surveys carried out via means of a conjoint analysis). For this reason, the concept of a modular safe box was shelved for the time being.

Drawing CSL-framework would have highlighted the importance of the synchronization of production and the product structure from the very beginning. However, this was already apparent anyway. The framework model cannot pinpoint technological solutions for dividing the product so that it would have fit the existing production structure. The framework model would thus not have brought any new aspects to the issue.

4.7 Summary of the Fastems machine tool case

The sample case to be presented here is a product development project carried out in Fastems Oy 2001. At the time, three M.Sc. theses were being written for the company, related to the development of product development, sales, and the product range. From the viewpoint of modularity, the most important task was to develop the product structure for the machining centre.

A machine tool is a product in which the customer's requirements are product functions and the function-carrying elements are mainly assemblies. A function-based division into modules fits such a product perfectly. In this case, then, new methods were not necessary. However, the company strategic landscape framework points out an interesting issues. The focus of the development project has been very narrow. The customer's processes and the associated requirements have not been considered, which in this case has not been a problem, either. *Development work was mainly carried out in the domain of product structuring, where the regularities of the product design process are valid in the form of the principle of emphasizing functionality.* As long as the focus of the development work is this, the framework model will not yield to an added value. Drawing a CSL-framework model will, however, illustrate how bold a decision in the product strategy lies at the core of the development project. Despite the risks, the product development project succeeded in its entirety and aims were reached.

4.8 Summary of the Profile ambulance case

In 2007 our research team took part in development project of a new ambulance family in Profile Oy. According the schoolbooks the functional division was proposed. As the functional division did not show results that could be applicable, a second round was made by using the customer variation as a starting point of the division. This division was applicable and the product family was made according it. Using the CSL-framework right from the start, would show us there was very little critical relations, which originate from variant functionalities.

4.9 Summary of the Ponsse forestry machine case

This company underwent a radical change from 1995 onwards. The entire model line was redesigned, while a product data management (PDM) project was carried out in the company. In 1996, the chopping machines Ergo HS16 and Cobra HS10 were launched. The following year, the forwarders Buffalo S16 and Caribou S10 were launched. In 1998, the model line was complemented with the Bison S15 forwarder [12]. The machines in the model line were designed to form a product family that utilizes shared components and design solutions and whose versions could be produced and sold as a systematically configurable product.

The implemented product structure systematics had a simple principle and it strongly relied on standardization. The product structure division has been performed based on customer configuration. The first principle to determine the structure was the simplicity of management. This supported the fact that at the time of the interview, the company did not want to make heavy software/hardware investments in, like the configurator as an example is. Configuration task in sales had to be simple, and there had to be an opportunity to create the bill-of-materials (BOM) list directly from the configuration, without computer-based tools. This was solved by having only two levels in the configuration model and presenting the attribute data and the parametric values as module alternatives.

In the presentations, this product structure method was called a ”clothes line”. This analogue, “clothes line” is used to hang clothes outdoors to make them dry and borrowed for configuration context. The writers are familiar with the approach as being "the Ponsse clothes-line", even though the company itself did not use this name. The idea was that each product model has its own ”clothes line” where the modules possible for the products hang. It must be possible to perform configuration so that the module variations that correspond to the customer requirements are picked from the ”clothes line”. This approach led to a division which resembles a functional module division at first glance. However, there are differences between the approaches. In a functional division, for example, tires of the wheels would not form a separate module, as they are available from two manufacturers. This, however, was done in the case of Ponsse, and the tyres did no longer have attribute data.

The Ponsse product structure in 1999 resembled a function-modular product to the extent where even the authors had previously suggested it being as function-modular. However, here we have mistakenly examined the finished product and used it as the basis for the evaluation of the systematics of the product structure division. *The division into modules is not, however, based on the technical structure of the product, but the necessary customer variations and the selected two-level product structure systematics.* A modular division that fits the functional structure thus comes close to the implemented structure, but it does not prove the critical solutions for this case.

The Company Strategic Landscape framework model points out the key elements**.** The required simplicity of the product data management and the possibility to rely on expert production are visible. The framework model however does not show the product series division. The sought product structure was to make the sales structure of the product resemble the one used in production control. This can be seen in the CSL framework model.

5. CONCLUSIONS FROM THE CASES

The results of the industrial examples are summarized in the table next page. The table evaluates the opportunities developing the functional module structure and its rate of success in business operations. Respectively, it is evaluated whether the key criterias are shown in the company strategic framework models created. Finally, the superiority of the framework model approach is evaluated.

In principle, it is possible to form a function-based modular structure for the products in all the sample cases. Of the eight cases, however, it clearly lead to a profitable result for the business environment in only one (with a reservation, two). In six cases, the result was not the desired one. Examining the examples in the framework model would have indicated the guidelines for the development of the modular structure in five cases. In three cases, the framework model would have shown the challenges of the operational situation, but not been able to directly show the technical solutions necessary.

Based on of this observation material, we can conclude that the functional structure is not an essential starting point for forming a modular product architecture. This is because the functional structure is related to the transformation implemented by the technical solution. Therefore, it is a dominant element in the area of product structuring. In a variant modular product, the modularity of the product is no longer only related to the transformation implemented by the technical system. In strong terms, modularity does not exist in the mere area of product structuring. A value chain in which a technical system is included as a part, as well as the production process that provides the instantiation of the technical system must also be considered.

TABLE 1: Applying function-based modularity and the company strategic framework in defining the modular structure in the sample cases

CASE	Is it possible to define function-based modular structure?	Is function-based structure relevant to business goals?	Can the important topics for modular structure be seen in the CSL-frame model?	The usefulness of the frame approach versus function based approach
Drilling rig	YES	NO	YES	BETTER
Truck	YES	With reservation yes	YES	BETTER
Diesel locomotive	YES	NO	With reservation yes	With reservation better
Passenger ship	YES	NO	YES	BETTER
Safe box	YES	NO	With reservation yes	No difference
Machine tool	YES	YES	YES	No difference
Ambulance	YES	NO	YES	BETTER
Forestry machine	YES	NO	With reservation yes	BETTER

6. DISCUSSION

It now seems obvious, that designing a product and designing a variant structure of a product family are totally different tasks and thus require different methods. Some proposals how this should be done do already exist. For example in the VDI standard 2206 ”Entwicklungsmethodik für mechatronische Systeme” from 2004, it is proposed to use systems engineering V-model (See e.g. [27]) as outer loop of the design and systematic design method as an inner loop. In this work, the V model is called the main cycle ”*Makrozyklus*” and the processes of systematical design (*problemlösungszyklus*) within it are called microcycles ”*Mikrozyklus*”. [31]

In this paper we have proposed CSL-framework, which is used to identify the requirements for variant product family architecture. This tool is currently under development and the ultimate goal is to develop method that produces not only the requirements, but an concept of the suitable architecture as well. One possible methodology for this is value chain analysis which has been developed 2006-2008 and is first published in 2009 [22].

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