Modularization
Fact-Based Design to Increase "the Room to Maneuver"

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Abstract. There is a common argument that modularization is one of the most important enablers for combining flexibility and customization with cost efficiency for manufacturing companies. However, our research indicates that companies not necessarily exploit the advantage of modularization. The reasons for this could be many, but a major explanation is that the companies very often have a vague understanding of what modularization really is and how the process should be. We have also experienced that the methodologies for modularization could be very time-consuming, producing a large number of e.g. excel sheets, but not necessarily data and facts. To this picture we also need to add that the companies, their products, production processes and stakeholders, represent constraints of what they can actually do when it comes to modularization – "the room to maneuver". Our presumption for successful modularization is a fact-based approach not only making decisions more robust, but also increasing "the room to maneuver".

Keywords: Modularization, manufacturing, fact-based design.

1 Introduction

Customization is one of the potentially most important competitive advantages for manufacturers in high cost countries such as Norway, especially when it is combined with innovations and frequent product introductions. Mass customization [5] and modularized design/production would normally be key elements in a strategy to meet such challenges. Among academics, this has been in focus for quite some time, and has become a kind of buzzword for companies. However, even if there are examples of manufacturing companies that has fully adapted modularization and exploited much of its potential, there is still a very long way to go within manufacturing.

The overall objective for the R&D project "Innovativ Kraft" is to reveal, create and combine the different presumptions and requirements for effective product- and process innovations. The focus is on fact-based processes and capability-sharing within a network of manufacturing companies. Our hypothesis is that modularization is a very important enabler and represents a common thread in Innovative Kraft.

Sharing capabilities requires that it is easy to transfer products or parts of products, e.g. modules, between capability owners. In this picture we have a broad definition of capabilities covering test-facilities, tools/machines, software etc. that when it is combined with knowledge and skills, represent a competitive advantage for companies. Modularization and a flexible product architecture make it easier to share capabilities and create a common innovative force within a network of companies. However, what we have experienced is that modularization as such still is a field where research and methodologies have a way to go to become the common recipe for manufacturing companies in product- and process development.

Even if companies talk about modularization in design and production, we see that they are taking methodological shortcuts in product development. The focus is to a much greater extent aimed at parts and pieces rather than on functions, platforms and the product lifecycle. There are many reasons for this, but we believe that much of this is explained by the need for better methods, where e.g. the need for data and facts into the modularization process are better catered. Companies are also operating in a world of constraints (and opportunities), where different stakeholders, technologies etc. are premise providers in the development process. Not least represents suppliers and other players in the supply chain a room to maneuver for the companies' modularization.

The purpose of this paper is to explore the way manufacturing companies approach modularization, challenges and opportunities they meet in these processes – their room to maneuver. We also present some hypotheses on what could improve the modularization process. The reference for our research is the

projects Innovative Kraft and Module Wrapped Data (MWD). These Two Norwegian R&D-projects aim to improve innovation and development by combining modularization and fact-based processes.
The projects are at an early stage and so far the activities have mainly been to develop hypothesis, challenges, and how to approach them in concrete contexts. The projects are closely related to what is happening in the companies (case studies) and the researchers aim to participate in the product development processes in order to improve them through action research. There have been workshops, and more technical design activities involving the researchers. Literature studies have also been important for the project (and this paper) at this stage.
Section 2 presents theoretical perspectives on modularization. Section 3 presents the R&D-projects while Section 4 discus our findings. Section 5 concludes.

2 Theoretical Perspectives

2.1 Modularization

Modularity allows part of the product to be made in volume as standard modules while product distinctiveness is achieved through combinations or modifications of modules. Modularization could bridge the advantages of: (1) standardization and rationalization, (2) customization and flexibility, and (3) reducing complexity [2].
To develop a modular product platform is a comprehensive process. It is both time-consuming and costly, and for many businesses it is a completely new way of working with product development. Often you have to plan even further ahead than you otherwise would have done, and are thus vulnerable to radical changes in the market. If the product does not yield expected/projected results, you risk being left with an even greater economic loss than would be experienced by conventional products [3].
Module-based design is when you make a product platform consisting of modules connected together via common interfaces. To take full advantage of modularization all modules should be planned in relation to replacement due to development. A good example of this is Sony's Walkman, where a good product platform with opportunities for replacement of various modules without changing the whole product, was designed. This requires time and resources for initial planning and design, but in the long run this will enable reduced development costs because they do not have to change the entire product [4].
Modularization also impacts the whole lifecycle of products as modularization enables real-life up-, side- and downgrades of products based on their use real-life in the lifecycle itself ensuring the continued use of the products [10]. This is now further enabled by the possibilities of IoT, Industrie 4.0 and the low cost of sensors, computing power and data-handling and transfer. This will impact the logistics and supply-chains as well as the requirements for information systems as these now must handle not only sourcing products and services, but also customized upgrades. Thus, modularization together with the ICT-developments the later years, yields new business-areas and creation of new service-concepts.

2.2 Approaches to modularization

There are a number of different methods of modular product development. A distinction is often made between component- and function-oriented modularization. Component-oriented modularization has a structure that focuses on an evolutionary design, architecture, components and customizations, while function-oriented modularization has a structure based on design, requirements / expectations, functions and modules [5]. The most fundamental methods, which originate from component- and function-based modularization are DSM, Function Structure Heuristics and MFD [6].
Design Structure Matrix (DSM) is a known method that can be used in conjunction with modular product development. This method is based around a matrix that provides a simple, compact, and visual representation of a complex system. DSM is a tool or technique to decompose systems, and used to visualize links between components. Therefore, this method is suitable for products where it is advantageous to be able to handle a system based on its components, and where on the links between components is important [6] [7].
Function Structure Heuristics are based on a model that is used to identify the modules based on a functional description of a product. This is done by setting up the product or system in a functional

structure diagram, where product functions divided into several sub-functions, which are then put together to form a functional model of the product. After this, a product development process in which one first goes through two steps in a functional modeling phase, and then to proceed through two steps in a product architecture phase [6] [7].
Another method focusing on the module's function is Modular Function Deployment (MFD) [2]. MFD involves analyzing the various matrices one uses to describe the relationship between customer requirements, product features, technical solutions and modular drivers. The method can be used to develop complex systems with the associated complex modules [6].

2.3 Bringing facts to the modularization

A systematic approach needs knowledge from people that knows customer demands, service requirements, and also from those producing the products. Concurrent engineering could be a key to mobilize and capture this knowledge [8]. An important part of the knowledge of the company is embedded in the products and reusing modules knowledge saves time and money. Also, reuse of engineering specifications, testing, process engineering etc, may lead to the desired effects by blurring the boundary between knowledge management and traditional modularization [9].
The tendency towards a more abstract understanding of modularity is further strengthened by the fact that modularization in an industrial context can be seen as reuse of engineering and employee resources for companies that are increasingly aware of knowledge as a competitive advantage [5]. An important part of the knowledge of the company is embedded in the products and reusing modules knowledge saves time and money. It is not necessarily the finished, physical modules that are reused in order to gain the benefits.
As more and more data related to products are available from a myriad of sources, so is also the potential to bring more facts into the modularization process. This is illustrated in the figure below, where examples of fact-sources are illustrated. A major point is that it is actually the facts brought into the modularization process that make the "wheel go around". The different methods for modularization presented in 2.2 all have their proper procedures, steps, templates, input requirements etc. However, as discussed further in the rest of this paper the question is to which degree these methods are efficient when it comes to facts and adaptivity for manufacturing companies.

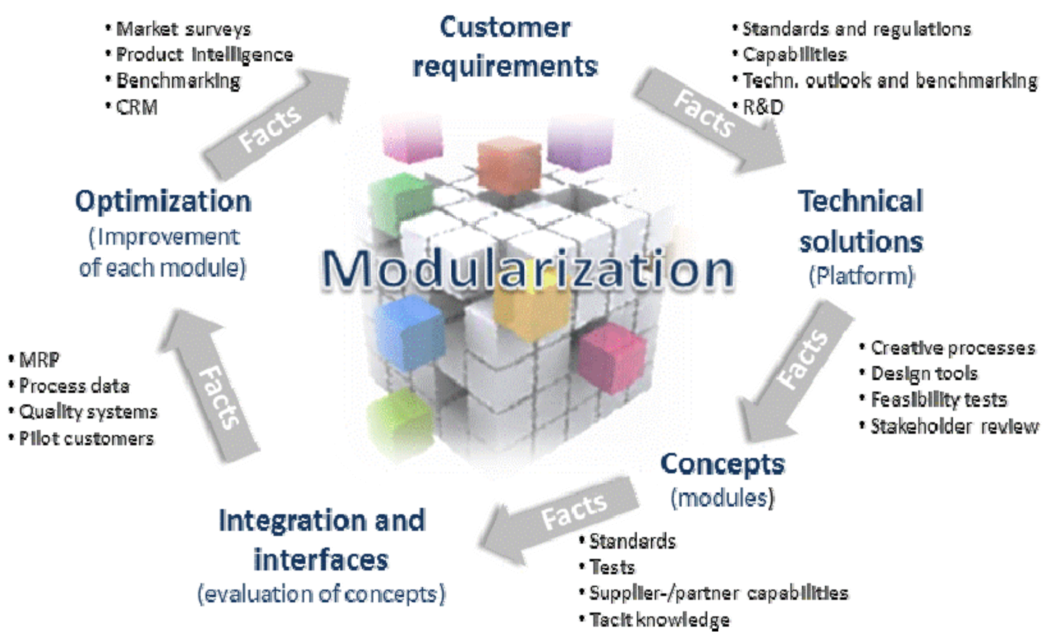

Figure 1: Modularization - Bringing facts to the process

3 The two case R&D-projects Innovativ Kraft and Marin Platform

Innovativ Kraft is a four year Norwegian research project co-financed by the Norwegian Research Council and the participating industrials. The overall objective of the project is, based on each company's innovation processes and capabilities, to develop solutions that give increased access to resources, competences, equipment etc. and knowledge to these processes. This will be a result of concrete solutions for development and sharing of capabilities between the participating manufacturing companies and between companies and R&D organizations.

The initial companies in this project are all part of the a cluster of mechanical engineering companies in the south eastern part of Norway called STN. Our hypothesis is that a major prerequisite for targeted capability development and sharing of capabilities, is modularization. The argument is that modularization enables separate testing and development of parts (modules), thus collaboration and outsourcing of these activities, hence sharing capabilities.

Innovativ Kraft also aims to improve the modularization process by focusing on new solutions for identifying, collecting, and structuring/analyzing data - metadata. SINTEF, BIBA, Inventas and the University of Agder are the research partners in this project. The reference case for this article is one of the participating SMEs that are developing a new type of incinerators.

The same research partners are central in another project called Marin Platform where the focus is on modularization methodologies and platform development. The industrial partners in this project are mainly within the boatbuilding-industry.

For both projects the researchers have been active in product development creating cases as the empiric bases for the research, but there have also been conducted surveys among the companies. So far our work has mainly been focusing on exploring challenges in the modularization process.

4 Perfect in theory – difficult in practice

4.1 Companies perception and practice towards modularization

Our experience from several research projects within product development is that modularization is perceived as a good approach among manufacturing companies. Many of these companies also claim to do so, arguing that they focus on reuse of parts, interfaces, product families, and so on. However, our impression has also been that these companies to a very little extent have implemented a structured process or distinct methods for modularization.

This was also the situation for the Innovative Kraft case-company developing a new type of incinerator. When the researchers introduced the MFD-approach to them, this represented something completely new when it comes to structure and documentation. Another partner in the MWD-project also claimed to focus on modules, but had no structured way to e.g. bringing facts to the modularization process.

Even if only 43,8% (7 of 16) of the companies in the STN-cluster responded to our initial survey, we gained more knowledge about the companies' attitude and understanding of modularization. All companies responded that they mostly deliver customized products, but only two responded that they focus on modularization, while four companies responded that they "sometimes do". Even though the companies responded that they to some degree had a functional focus only one of them had heard about the MFD methodology.

There are wide variations between STN-companies' attitude and use of modularization, depending on size, industry, place in the value chain, market strategy etc. However, we are confident that our hypothesis, that modularization has a bigger potential than we have seen so far, is strengthened. Companies' knowledge about modularization and how to work on it have to increase, at the same time, approaches and methodologies need to become more closely aligned to company- and industry-specific challenges.

4.2 Modularization as a fact based process

One of the practical challenges of modular product development is to get people involved in the process to understand the importance of documentation. In particular the initial modular product development process that requires clearly more planning and discipline than many companies have been used to. However, the platform design and modules that could be reused give the possibility to harvest on these initial development costs in the next turn as product development (and improvements) becomes less time consuming and costly. This was definitely the experience from our business case developing a new type of incinerators. In the initial phases of MFD where user requirements should be prioritized, the product developers found the documentation very time consuming and had little motivation for working on extensive documentation with scoring columns. However, further into the process where functions had to be defined, the ability to track decisions (and arguments) based on the heavy and available documentation, proved to be very valuable.
For the case-company, MFD as a product development methodology was recommended through the Innovative Kraft project. This enabled them to learn of a product development method which was supposed to be well suited to their product. The company gained, through its participation in Innovative Kraft, access to valuable knowledge that could otherwise become difficult to acquire. This knowledge should also be transferred to the other companies in the Innovative Kraft project.
Since the focus is more and more on modules as knowledge containers, and not just only as physical objects, the way to capture facts to the modularization processes seems critical and is an improvement area for most of the functional-oriented modularization methodologies. The most common methods we see today are relaying very much on complex scoreboards based on subjective qualitative assessments from a limited number of people. If relevant data could be (automatically) captured and addressed directly to the product, and module-based product development, this would be a major step forward for todays' methods. More facts into the processes do not only make design decisions more robust and traceable, they also make it easier to transfer product information. Hence modules fulfill better the roles as knowledge containers when they are based on facts.

4.3 The room to maneuver

With regard to how the case company relates to "make or buy" decisions, a modular product development strategy is apparently a good choice. This strategy can simplify procurement as the company can relate to a provider of a module instead of a variety of vendors that supply different components. Here one can save lots of time and resources. In addition, you ensure qualitatively good solutions by selecting modules from suppliers who have the function as its core business, and you can also save resources by modules tested where they are produced.
In todays' manufacturing e.g. lean-based, a close collaboration to suppliers and the value chain is important also in product development. However, the challenge is greater when you are a small player in the value chain and can do little to control the others. One has to a much greater extent to choose between what exists in the supplier market and has far less ability to control their choices (at least when vendors are large).
Following a stepwise functional approach such as our case-company did was challenging when moving from functional requirements to concepts and definition of possible modules. In the ideal world the company should develop the optimal concepts/modules, but in the real world the company often has to accept what is available on the supplier-market or what their suppliers decide. But, what is available on the market or from the suppliers does not necessarily fit the requirements from the modularization process. A challenge for the development of this new incinerator was that doing the whole development and production in-house was too resource-intensive for the case-company. At the same time, the suppliers they knew, did not have the relevant modules available or were not willing/able to develop them.
Interviews with three of the suppliers of the company showed big interest for collaboration and involvement in these kinds of development projects. The challenge is how this could be practiced, and how to build a structure for this kind of collaboration. Efficient and well-documented processes seem to be very important enablers.
By utilizing MFD, the company obtained a much better documentation on the choices and assumptions. This means that it is easier to create and distribute facts together with suppliers. In this way suppliers are aware of the background to the functions they provide and can contribute to optimal modular solutions. A supplier may express requirements for interfaces on the basis of their knowledge and lead to the various

features of the product goes along well. Good structures for collaboration and knowledge transfer will also convey expectations of external innovations in connection with the individual modules.
The case company moved into an unknown area of possible actors when they started the development project. They had some of their established suppliers on board, and knew about some other possible partners. However, they needed an efficient system to gather data and create knowledge about new and maybe better partners, relevant technologies etc. A major lesson learned is that fact-oriented modularization processes also should involve solutions capturing more facts about the product-/markets, regulations, actors and potential partners.

5 Conclusion

The Innovation Kraft project aims to develop mechanisms enabling collaboration between companies in development processes. Modularization is regarded as a key factor to make that happen. What we have learned so far is that even if modularization has become a common term, the content of this term is very fluffy for many companies. When we in one of the business cases in the Innovation Kraft project have used a function-oriented development process (MFD) we have experienced many challenges both related to the methods as such, and the need for collaboration between companies. We have seen that even if there are structured methods for modularization, such as MFD, it is not evident that the documentation and templates work efficiently internally and as a basis for involving partners in the modularization process. An important conclusion and basis for further research is that fact-based processes where data collection and documentation is a much more integrated and automated part of modularization.
A more fact-oriented modularization process not only makes the decisions more robust and traceable, it also enlighten options, alternative solutions etc. When modules in this way become more of knowledge containers they also enable better collaboration with suppliers and other stakeholders. Hence, a more fact-based modularization process could improve "the room to maneuver".

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