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A HOLISTIC APPROACH TO MODULARIZATION

Fagerström, Björn and Jackson Mats

Abstract

This paper presents a holistic model for analyzing the phenomenon of modularization. To evaluate this suggested model a case study has been performed at four different companies from the mechatronic industry. The case study investigates current modularization initiatives at different levels, and what results the companies have achieved from their modularization efforts. It has been concluded that the concept of modularization is rather fragmented and perceived differently at different levels at the case study companies. It has also been concluded that the full effects of modularization have not been achieved, due to lack of a common approach and strategy. Local modularization efforts could have some impact but there is a certain risk for sub-optimization. It is difficult to evaluate a modularization program in economic terms. Initially, modularization increases the cost and the benefits at a later stage are quite difficult to quantify, which could result in uncertainty during the implementation.

Keywords: Modularity and standardisation, Product Planning, Product Architecture

1 Introduction

The competition of today is truly global with fragmented markets and customers expecting to get the best product at the best price and immediate availability. Meeting customer demands requires a high degree of flexibility, low-cost/low-volume manufacturing skills, and short delivery times. Modularization has often been suggested as one major innovation for the industry to compete in a turbulent business environment. Product modularization is widely recognized as a key in realizing economic and commercial goals of a product program [1]:

- Economy of scale in production - potential for cost savings, from volume production of standardized modules and better management of complexity in the assembly plant, due to sequenced deliveries of modules
- Reduction of delivery time due to the possibilities of a late customer order point
- Enhancement of speed in the product development process – e.g. more efficient product development, with suppliers of focused competence able to innovate more quickly and to distribute the costs across multiple customers
- Product modularity enhances organizational learning
- Potentially lower costs from outsourcing production to low-cost countries

Despite many reported success stories there still seems to be confusion about managing modularization initiatives to obtain specified benefits [2]. Research at MIT suggests that potential savings in modularization are still elusive for most automakers. The reason for this

is that to few modules are being standardized across models, and automakers are still being heavily involved in product design through shadow engineering of suppliers[1]:

> *"The absence of a clear cost advantage for modules, combined with the inherent technical difficulties of changing the highly integral product architecture of an automobile, has taken the shine off modularization. Nevertheless, a number of factors could still accelerate the move towards modularity, including automaker efforts to shift investment risk to suppliers, the increasing use of information technology (often itself highly modular) within vehicles, and the possibility that consumers will show a strong interest in built-to-order vehicles"*

Many companies experience significant problems in coping with modularization due to an incomplete and fragmentary understanding of the phenomenon. It is a need for further empirical research that takes a more holistic viewpoint of modularization [2]. This paper suggests a holistic model for analyzing the phenomenon of modularization. To evaluate this model we have interviewed four companies and investigated modularization initiatives at different levels, and what results that they have achieved.

2 Related literature

It has been argued in the introduction that the concept of modularization has to be analyzed with a holistic approach. The literature section will thus discuss modularization at four different levels at a company: the strategic level, the product planning level, the product development level and finally the production level. In order to understand and manage these levels there is also a need for integration and coordination.

2.1 Strategy and modularization

Modularity is a strategy for organizing complex products and processes efficiently [3]. The desired effects of modularization have changed, but at a high level, modularization is still about rationalizing business [4]. Standardized interfaces facilitate for module suppliers to compete on a global market. An important strategic decision is to decide which solutions and knowledge should be reused, in order to improve the business performance. Modularization is not what a module is, but rather what it does, what effects are delivered. From a business rationalizing perspective, that could be considered as achieving more with less. The strategic level of modularization involves visionary understanding of customers including e.g. strategic product planning, complexity management, market understanding, new technology, and core functions. It creates both, the requirements for research and development and the input for business planning, which analyses the economic efficiency of strategic business options [5].

Another strategic view of modularization is that it has basic effects in three different dimensions – to create commonality, to limit complexity, and to create variety [4]. Resource leverage includes reuse of resources to gain rationalization benefits as e.g. not inventing the wheel over again, working faster and better by learning effects and supporting tools, reducing risk by using well known solutions, and reducing internal variety. Limitation of complexity includes decoupling tasks and increase of overview by breaking down into independent units, the possibilities of conducting parallel work, the possibilities to distribute tasks, better planning, and simplicity to understand, grasp and manipulate. Variety includes providing a well-fitted product to a customer created by a combination of modules.

[1] IMPV – MIT: http://web.mit.edu/ctpid/www/imvp/frame.html

2.2 Product planning and platforms

Modularization has a close link to product platforms, platform thinking and management of product families [4]. Some of the main benefits from a platform strategy include reduced development and manufacturing cost, reduced development time, reduced systematic complexity, better learning across projects, and improved ability to upgrade products [2]. A platform could be defined by a set of products. These assets can be divided into four categories: components, processes, knowledge, and people/relationships [6].

Determining the product architecture is a key activity in platform development and also for modularity. The platform will give the intended product architecture but also propose alternative architectures. Sub-systems or modules need to have well defined interfaces in order to release different products from the platform. The evaluation of the platform can be done with modularity in focus, in which the module drivers are essential. Also the needed variety of the platform needs to be defined in early phases. Determined shared functions between platforms allow for development of multi-platform sub-systems that can be separately developed and tested.

The advantage of having well defined modules already at platform level is that the product development, production planning and logistics can start to work in parallel. Additionally, this allows for suppliers to be involved early in the process. This may also permits for competition between module suppliers [3]. The disadvantages are that the obtained knowledge for the entire system may not be possible to apply, due to already defined modules.

2.3 Product development and modules

The product architecture is often described in functional terms that then are realized by physical building blocks. The functional aspects of the product are frequently discussed at the strategic and platform level, but the interface aspects are often secondary. It is emphasized that it is of similar importance to discuss both the interfaces and a certain module. This is an iterative process in which the architecture is created during a continuous dialog between modules and interfaces. An important question is when and how the product architecture is made explicit. Also suppliers should be involved in this process, as they often have the important experience and knowledge that are needed in order to define efficient interfaces.

The product is often characterized as a modular or an integrated architecture. In reality, we often have different combinations of both a modular and an integrated architecture. Modularization can be defined as *"Decomposition of a product into building blocks (modules) with specified interfaces, driven by company-specific reasons"* [7]. Modularization is very similar to functional decomposition, but the driving force in modularization is provided by the module-drivers, which are lifecycle orientated [7]. Modularization often refers to independent units and some authors even refer modules as standardized components, or standardized interfaces. Another definition is to which level a module is interchangeable for creating variants [4]. It should also be emphasized that modularization may increase the number of parts, weight and cost. This frequently occurs when interfaces should transmit functions.

2.4 Production and modules

During the 1990's the objective of companies has changed to selling customer oriented variants and keeping delivery cost low. To enable this, approaches like mass production and delivering one-of-a-kind products are not adequate any more. A common view is that future production systems need to adapt quickly to changes and that this can be achieved by a decentralized autonomous organization [8].

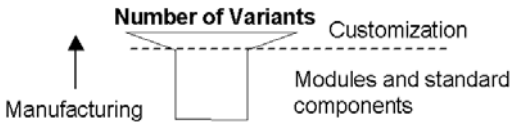

Figure 1. Mass customization and modularization

Within future production system philosophies modularization is often mentioned as one important enabler. Modularity facilitates quick responsiveness and adaptations to changing conditions by allowing reconfiguring of solutions and resources. Mass customization is one visionary production concept connected to configuring modules or standard components to a customer specific product still having an efficient manufacturing. Manufacturing of standard components and modules can be done industrially, with benefits of scale, see figure 1.

Modularization gives possibilities through late customer specific order-point within the production system and in this way reducing complexity and variety within production. The production system can be organized into the specific modules of the product, giving autonomy and possibility of scalable and reusable production modules. Also, if we modularize the product it is possible to co-operate with a supplier both in regards of the design and in regards of the actual production.

2.5 Integration and coordination

An understanding of design coordination and integration is also essential in order to understand how modularization has been implemented at different levels in the case study companies. The purpose of design co-ordination is to manage and control the complexities of the design process [9,10]. Coordination concentrates on planning, decision-making, organizing, and controlling the work of others, and on the loose interaction between people. A common language for communication is crucial for efficient information exchange. Coordination refers to people, whereas integration refers to products, components, and tasks.

Integration can be seen from many perspectives, such as the task, activities or sub-systems. The efficiency of an organization is dependent on its ability to manage the interfaces within the system architecture and to do so by a process of integration. The goal for the integration of components is to produce an entire product. As people are humans, not components, it is their activities and tasks that may be integrated [10]. A common task definition and collective goal settings through mutual communication among people are necessary if the term integration is to be used fruitfully. The concept of integration needs to prevail over a long period of time if it is to be distinguished from the concept of co-ordination. The terms ‘integration’ and ‘co-ordination’ could better be explained by the following questions; *What* is integrated, *Who* is coordinated and *Whose* work in terms of tasks and activities is integrated.

3 A holistic approach to modularization

Many industries have for a long time had a degree of modularity in their production processes, but a growing number of them are extending modularity to the design stage. Furthermore, an increased number of companies use modularity to achieve competitive advantage, such as within the computer industry and automotive industry [4]. In this context, a more comprehensive and holistic approach is needed to fully utilize the advantages of modularization. Modular engineering is not solely related to the artifacts, modularization is also about knowledge and activities [4, 5]. There are some previous authors [1, 5] that have proposed holistic models for evaluation of modularization initiatives, see figure 2.

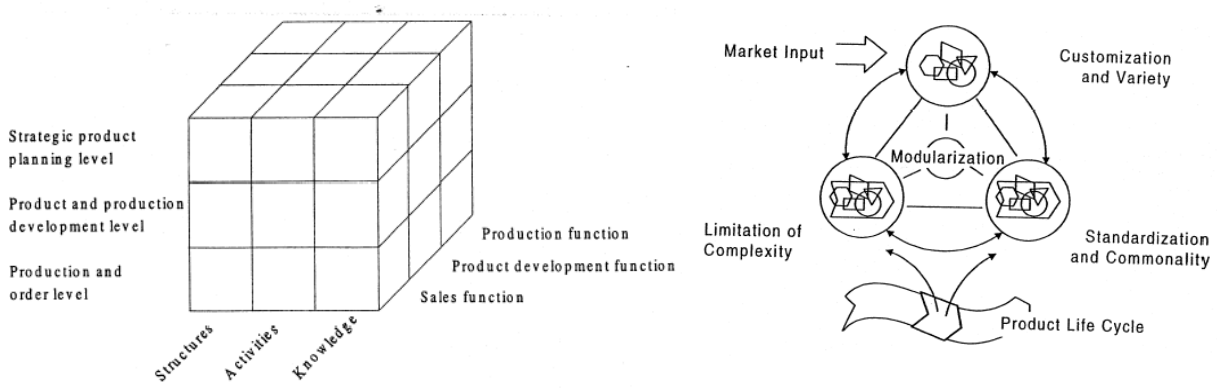

Figure 2. Holistic models for evaluation of modularisation initiatives [1 left: 5 right]

The model that is used in this paper (Figure 3) has similarities to the framework presented in figure 2 (left) [1]. The proposed model consists of a strategic, tactical, and operational view of modularization in relation to the competitive environment, customers, and suppliers for a certain company. In order to understand and manage these levels there is also a need for integration and co-ordination. The strategic level of modularization involves visionary understanding of customers including e.g. strategic product planning, complexity management, market understanding, new technology, and core functions. The tactical level of modularization is concerned with a detailed product planning. The operative level of modularization consists of product and process development. The model does not explicitly show life-cycle aspects, as shown in the model presented in figure 2 (right). Anyhow, the life-cycle aspects have also been discussed during the interviews.

4 Research approach

4.1 Methodological approach

Increased complexity stresses the need for models that could be used to develop a shared understanding. Systems theory is a promising effort to deal with this problem, where an understanding of a system cannot be based on knowledge of the parts alone. The whole could be greater than the sum of the parts and contents are not solely in the parts.

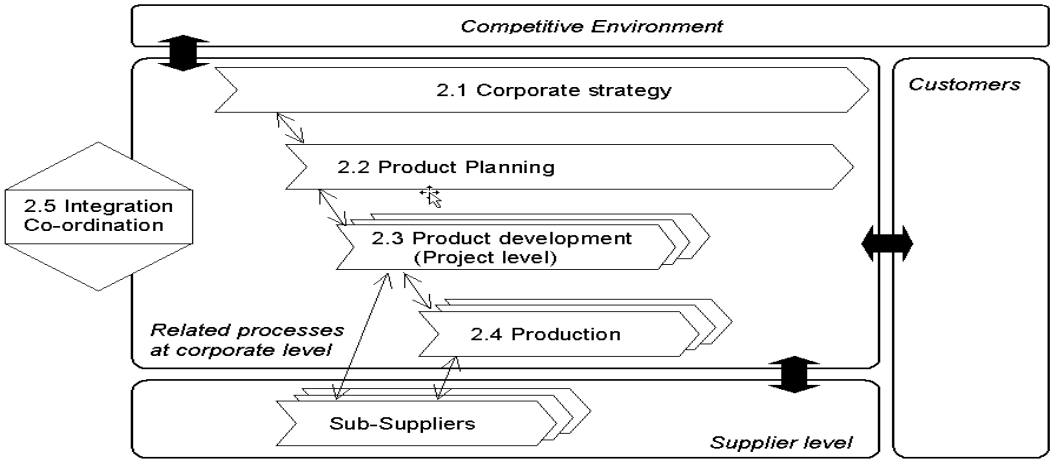

Figure 3. A holistic model for evaluation of modularization

It is also important to see the processes of change for the system, rather than taking snapshots. The system in this work is an artificial (not natural) open system with loose couplings. In open systems, the correlation between a given 'input' and an expected 'output' could be difficult to find. Furthermore, 'cause' and 'effect' are not always close in time and space [12]. The real leverage in most management situations lies in understanding dynamic complexity, not detail complexity [11].

Knowledge obtained through the systems approach is not looked upon as being general in the same absolute meaning as knowledge obtained through the analytical approach. In systems theory, knowledge is connected to one or several classes of systems or to specific system phenomena. As such, we can speak of system-dependent knowledge. The system theory knowledge is valid in particular contexts and in similar systems.

4.2 Collecting data

In general, case studies are the preferred strategy when 'how' or 'why' questions are being posed, when the investigator has little control over events, or when the focus is on a contemporary phenomenon within some real-life context [13], which is relevant for this work. Case studies are often criticized for lack of statistical reliability and validity. Furthermore, it is argued that it is not possible to test the hypothesis. To overcome this dilemma, it is increasingly important to select a representative case and validate the result continuously, and not simply at the end of the study. It is also important to describe the actual case carefully and only draw conclusions that are valid only for similar systems. The need for case studies and a systems approach is illustrated by [12]:

> *"Human beings like business situations are unique, however, there are uncontrolled elements, such as customers and competitors, that create unexpected results."*

The pre-understanding of the investigated phenomena is important in order to facilitate for an accurate discussion. It is assumed that knowledge is created jointly during the interview, between the interviewer and the respondent. The interpretation of the interview is partly done as the interview progresses. To overcome the dilemma with secondary subjectivity, at least two persons will be interviewed at each company. Secondary subjectivity is the phenomenon when the respondent gives a subjective statement that is interpreted subjectively by the interviewer. In order to increase the validity, a ‘multi-method-approach’ will also be used.

As a complement to the interviews a survey was also sent out in advance and discussed during the interviews. Open-ended questions will then be used during the interviews. Open questions will give good explanations for how they are working and that will reduce the risk of expected answers that could occur in structured interviews. The concept of modularization is well known and it is a risk that the interviewee will give answers related to how they should work, not how they are working, which the interviewer must be aware of.

4.3 Interview questions

The interview questions were divided into four different parts according to a suggested holistic model for analyzing the phenomenon of modularization. The open ended case study questions that has been used for starting the discussion are presented below:

Strategy:

1. Is modularization part of strategies and goals?
2. What are the purposes of modularization - quantify the strategic reasons for modularization?
3. To what degree have the results been accomplished?
4. Has work been done integrated or coordinated?

Product Planning:	1. How is modularization related to your product planning process? 2. What are the purposes of modularization - quantify the product planning reasons for modularization? 3. To what degree have the results been accomplished? 4. Has work been done integrated or coordinated?
Product development:	1. How is modularization related to architecture and interfaces? 2. Has work been done integrated or coordinated?
Production	1. How is modularization related to the production process? 2. Has work been done integrated or coordinated? 3. How are product changes implemented?

4.4 Case study companies and interviews

The case study involves four companies within the mechanical and mechatronic industry. All companies have their own marketing/sales, product development and production department. The product could be considered as complex. The number of employees is between 220 and 2000. Between two and five interviews were carried out at each company.

Company 1 – interviews were conducted with representatives from the engineering department and the production department.

Company 2 – interviews with representatives from product development and manufacturing.

Company 3 – interviews were conducted with representatives from product development, product planning, and purchasing.

Company 4 – interviews with representatives from the marketing and engineering department.

5 Case study results

The interview results are presented according to the same structure as the interview questions. The interpretation of interviews has been done continuously as the interview progresses.

5.1 Strategy – case study results:

In company 1 modularization is not in the company's strategy. The strategic reasons for modularization were expressed as reducing complexity, reducing lead times within production and product development, customization, and the possibilities to offer new variants. Cost, distributed product development and reuse of technology were not expressed as drivers of modularization. The results and implementation of modularization was estimated to be 50%.

In company 2 modularization is partly mentioned in the company's strategy. The strategic reasons for modularization were expressed as reduction of complexity, reduction of cost and lead times within product development, and the possibility to reuse technology and knowledge. Customization was not expressed as drivers of modularization due to the standardized products, which are sold in certain sizes and models. The results and implementation of modularization was estimated to be less then 50%.

In company 3 modularization is not explicitly expressed as a part of their strategy. The company considered distributed product development, reduced lead time, customization and improved quality as their most important strategic reasons for modularization. The achieved results from these strategic issues were implemented to over 50%.

In company 4 modularization has been defined as a strategic issue, also involved in their vision. The company considered planning, reduced complexity, decreased cost and lead time as their most important strategic reasons for modularization. The achieved results from these strategic issues were implemented to approximately 60%.

5.2 Product planning – case study results:

In company 1 product planning reasons for modularization were expressed as future upgrades/developments to some extent, different specifications to different customers and customer segments, and service and reparations. The results and implementation of modularization in product planning were estimated to be less then 50%.

In company 2 product planning reasons for modularization were expressed as short lead-times through parallel development, cost, and separate independent testing. The results and implementation of modularization in product planning were estimated to be less then 50%.

In company 3 product planning reasons for modularization were expressed as future upgrades, service and reparations, carry over and separate testing. The achieved results from these product planning objectives were implemented to over 60%. The modules were not fully defined and the concept of modularization were not made clear. The product plan was developed in an integrated manner with their product development department, production and quality department. Information from other actors, such as customers, suppliers and authorities were coordinated.

In company 4 product planning reasons for modularization were expressed as shorter lead time, service and reparations, and modular production. The achieved results from these product planning objectives were implemented to less then 50%. Company 4 has defined modules but the interface specifications are not completed for all modules.

5.3 Product development – case study results:

Company 1 has a product architecture that is divided into modules. Interface specification exists on modules to some extent and demands and specifications are not divided down to a modular level. Modules are interchangeable within the product family but there are no standardized modules with identifications.

In company 2 the product architecture is divided into modules. Interface specification on modules exists to some extent and demands and specifications are divided down to a modular level to some extent. Modules are interchangeable within the product family and there are standardized modules with identifications.

Company 3 has an interface specification for most of their modules. The product architecture consists mainly of defined modules. Requirements are presented at modular level for most of their modules. The company saw possibilities to use the principle of interchangeable modules with different functionality, but not implemented at present. If a designer has problems to meet the requirements at modular level, the negotiation and balancing of requirements with related modules are performed in an integrated manner. Most tasks between other module-teams were mainly coordinated and problems solved in an integrated manner.

Company 4 has a product architecture that is divided into modules, but with problematic interfaces. A lot of the functions are transferred over the interfaces and the modules cannot be designed independently, as the interface specifications continuously are revised. There are specifications at modular level but the interface specifications could be improved. There are few standardized modules and a high degree of customization. A lot of efforts and time is spent on discussions between module teams in an integrated manner.

5.4 Production – case study results:

Company 1 has modular workshops but modules are not part of the production planning. The modules are standardized – but the product is in some cases customized before delivery to customers. There is co-operation with product development but the process of changes in the product and in modules does not work well.

In company 2 there are no modular workshops. Still, modules are to some extent part of the production planning and the modules are standardized.

The production hall is partly built up as a modular factory at company 3. The company has a separate article number for modules. The production planning at company 3 also includes manufacturing of modules. Some modules are manufactured and tested by suppliers.

Company 4 has modular workshops. The modules are to some extent standardized, but a lot of customization often results in special procedures and additional costs. The company mentioned some life cycle oriented constraints that have a strong impact on the interfaces and that differs quite a lot from a production perspective. This often results in sub-optimal interfaces for the production and additional work.

6 Discussion and conclusion

The term modularization is defined and perceived differently at different levels in the case study companies. For instance, the production people one company saw a module as a sub-system that could be manufactured independently and preferably also tested independently. The marketing people on the other hand have a more customer-oriented approach and only modules that are customized for certain customers are seen as modules. This separate module should also have a correct module-specification, in order to negotiate with the customer.

During the interviews modularization was seen to be a very promising concept, but very difficult to implement. It is hard to evaluate the economic impact from a modularization program. Initially, modularization often increases the cost, as it is much more difficult to design a modular system than an interconnected system. Furthermore, the benefits at a later stage are quite difficult to quantify, which could result in problems during the implementation. Different organizational functions also have different viewpoints and it is not possible to reach consensus for definitions, interfaces, etc. Lack of management support is another reason for problems with implementation of a modular concept.

Modularization has only been explicitly defined as a strategic issue at one out of four companies. The other companies have been discussing strategic aspects of modularization but that has not been commonly agreed at highest level. Modularization is still a vague concept at the product planning level, even if two out of four companies have put some efforts to deal with this problem. It is a certain risk that modularization initiatives starts locally and that may have some effects but there is also a certain risk for sub-optimization. The strategic aspects of modularization are communicated with a more coordinated approach at all case study companies, which could be one of the reasons why so many people interpret the concept of modularization so differently. A more integrated approach might be needed in order to solve some of the misunderstandings that could occur with a coordinated approach.

It was concluded during the interviews that modularization needs to be considered in a life-cycle context. The optimal modules from a production perspective may differ from a structural, logistic, or testing perspective. This issue stresses the need for involving modularization in a life cycle perspective at product planning level.

It is concluded that the proposed model (Figure 3) could be used for evaluation and discussions concerning implementation of modularization initiatives. If the concept of modularization should be fully utilized a common and consistent strategy is needed. The product planning level needs to better define the modules and how to develop each module during the life cycle, and how to share modules between platforms. Requirements and interface specifications for modules is critical element in order to design modular systems.

The authors propose that future research are performed in the area of economic models for evaluation of modularization, methods for implementing modularization at strategy and product planning level and finally trade-of models for evaluation of modular product architectures in a life-phase system.

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For more information please contact:

Björn Fagerström, Pharmadule Emtunga, DanvikCenter 28, 131 30 Nacka, Sweden, *and*
Dep. for Engineering and Industrial Design, Chalmers University of Technology, 712 96 Göteborg, Sweden.
Tel: +46 8 58 796 710, Fax: +46 8 58 899 888, E-mail: bjorn.fagerstrom@pharmadule-emtunga.com