Tampere University

Janne Närhi

MODULAR PRODUCT IN A PLM SYSTEM

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ABSTRACT

Janne Närhi: Modular product in a PLM system
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A challenge in industry is the demand of a customer specific product with a reasonable price. Modular product is an efficient concept to answer the requests; companies that succeed with modularization projects have gained competitive edges. There are many theories about modularization in literature. Management of a modular product data is also discussed but the modular product design methods have not considered in detail. The modular design method ensures the implementations and maintenance of modularization benefits.

A modular product requires more sophisticated IT systems for efficient data management. The traditional product structures are inadequate in the context of modular products. The case company’s intention is to find a suitable methodology that answers its product design, product data management and product configuration needs. An implementation of a new architecture management will bring out requirements for the case company’s modeling methodology. The methodology needs to be adapted to serve the case company’s needs.

In this thesis the focus is on IT systems and management of modular product data. Recent updates in case company’s IT systems enable new methods and this study identifies the capabilities that support them. Restrictions and compatibility issues of IT systems are also discussed.

The offered modular design method based on requirements of the architecture management tool is validated and applied in the context of the case company’s products. Evaluations of suitable methodology according the experiences and discussions with design engineers are offered. The current set of IT systems and its roles are discussed. In this thesis a future scenario of responsibilities of the IT systems is shown. The principle of a modular product future recognition in PLM system is presented and the required modular product terminology is recognized. In addition to these results there is a discussion about future modular modeling methods and IT systems.

Keywords: PLM, modularization, modular product, interface, product structure, configurator

TIIVISTELMÄ

Janne Närhi: Modulaarisen tuotteen kuvaus PLM järjestelmässä
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Asiakaskohtaisesti räätälöityjen ja kohtuuhintaisten tuotteiden kysyntä on haaste teollisuudessa. Modulaarinen tuote on tehokas keino vastata kysyntään, ja modulaarisuushankkeissa onnistuneet yritykset ovat saavuttaneet kilpailuetuja. Moduloinnista löytyy runsaasti kirjallisuutta ja modulaarisen tuotteen tuotetiedon hallinnasta käydään keskustelua myös, mutta yksityiskohtaisista suunnittelumetodeista modulaarisille tuotteille ei löydy tietoa. Suunnittelumetodit varmistavat moduloinnin hyötyjen toteutumisen ja niiden säilyvyyden modulaariselle tuotteelle.

Modulaarisen tuotteen tehokas tietojenhallinta vaatii kehittyneempiä tietojärjestelmiä. Modulaaristen tuotteiden tapauksessa perinteiset tuoterakenteet ovat riittämättömiä. Case-yritys pyrkii löytämään sille sopivan ratkaisun, joka vastaa tuotesuunnittelun, tuotetietojen hallinnan ja tuotekonfiguroinnin tarpeisiin. Uuden arkkitehtuurin hallintatyökalun käyttöönotto tuo mukanaan vaatimuksia case-yrityksen mallinnusmetodologialle. Metodit on mukautettava vastaamaan case-yrityksen tarpeita.

Tässä työssä keskitytään tietojärjestelmiin ja kuinka niiden avulla voidaan hallita modulaarisen tuotteen tuotetietoa. Tietojärjestelmien viimeaikaiset päivitykset mahdollistavat uusia metodeja ja tässä työssä selvitetään niitä tukevia järjestelmäominaisuuksia. Myös järjestelmien rajoituksista ja yhteensopivuusongelmia käsitellään.

Ehdotettu modulaarinen suunnittelumenetelmä, joka huomioi arkkitehtuurin hallintatyökalun vaatimukset esitellään ja sovelletaan case-yrityksen tuotteille. Tulosten ja suunnittelijoiden kanssa käytyjen keskustelujen perusteella arvioidaan metodologian soveltuvuutta. Nykyisistä case-yrityksen tietojärjestelmistä ja niiden rooleista keskustellaan. Työssä luodaan tietojärjestelmistä ja niiden vastuista tulevaisuuden skenaario. Periaate modulaarisen tuotteen kirjaamiseksi PLM-järjestelmään esitellään ja modulaarisen tuotteen edellyttämä termistö tunnistetaan. Tulosten lisäksi keskustellaan tulevaisuuden modulaarisen tuotteen mallinnusmetodeista ja tietojärjestelmistä.

Avainsanat: PLM, modulointi, modulaarinen tuote, rajapinta, tuoterakenne, konfiguraattori

PREFACE

This thesis was written as a part of a modular product data management project in a case company. I want to thank the representatives of the case company for an interesting topic and the opportunity to write this thesis. I want to thank all the parties involved to this thesis and fellow workers.

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LIST OF SYMBOLS AND ABBREVIATIONS

BfP	Brownfield Process
BOM	Bill of Materials
CAD	Computer-Aided Design
CE	Concurrent Engineering
CIM	Computer Integrated Manufacturing
CSL	Company Strategic Landscape
DFA	Design for Assembly
DFMA	Design for Manufacture and Assembly
DML	Dedicated Machining Line
DSM	Design Structure Matrix
eBOM	Engineering Bill of Materials
ECN	Engineering Change Note
ECO	Engineering Change Order
ECR	Engineering Change Request
ETO	Engineered-to-order
FMS	Flexible Manufacturing Systems
IT	Information technology
mBOM	Manufacturing Bill of Materials
MIM	Modular Indication Matrix
NPD	New product development
PFMP	Product Family Master Plan
PLM	Product Lifecycle Management
PoC	Proof of concept
PSBP	Product Structuring Blue Print
PVM	Product variant master
QFD	Quality Function Deployment
RMS	Reconfigurable Manufacturing Systems

1. INTRODUCTION

The importance of adjustment into changing customer requirements has grown due to the increasing competition in industry. Traditional ways to address the increasing pressure for change from customers, legislation, suppliers etc. has become inefficient. Without modularity the attempts to fulfill changing demands usually leads to scattered and costly designs, longer time to market, poor quality and issues in maintenance.

Modularization for a product family is a powerful tool to answer the new requirements. Succession in modularization will source competitive advantages. By modularization inner variance in product offering can be restricted and simultaneously product assortment for customers suits better for the changing demand. Quality improvements and deliveries on time are achieved by focused resources to fulfill only the needs of the preliminary chosen customer. Modularization requires cultural change for the whole corporation to achieve wanted benefits. Therefore, the highest risks connect to the success of the mindset change among employees.

Creation of a modular product family itself is a challenge but product data management for it causes additional workload. The modular product data maintenance differs considerably from the traditional way. The recognition of a modular product in IT (information technology) systems is relatively new and standard methods and terminology do not exist. Every company has a unique set of IT systems and their maintenance can become complex.

The case company is implementing new IT systems into use to support a new data maintenance methodology. The author of this thesis is part of the team that has the implementation responsibility of the architecture management tool. The provided architecture management tool which will be linked to the case company’s Product lifecycle management (PLM) system, configurators and sales tools.

The responsibility of the author is to consider the influences of the new modeling methodology and the new architecture management tool. The author gathers the knowledge by literature review in the first part of the study. In the second part the provided modeling methodology and its impacts for the case company are considered. The feasibility study of the modeling methodology and proposed updates for IT systems are documented. In this thesis the emphasis of the scope is on the recognition of the product data in the PLM system and the new modeling methodology.

2. RESEARCH OVERVIEW

This chapter explains the objectives of the research. The background and the purpose of the research are explained. Also described are research questions and limitations.

2.1 Research background, objectives and limitations

In the case company there have been several modularity researches. Most of the earlier studies has been concerning the specific product families. More detailed information about the studies in the case company are described in Chapter 6.2.

In the case company several IT systems for product data management are going through an upgrade process at the same time with this research. There is also ongoing data migration project between product data management (PDM) systems in the case company. The upgrade processes are results of obsolete IT systems and new requirements for data management in the case company.

This research is a small part of ongoing studies in the case company. The scope of the research is limited to couple of product families. The focus of the research is only loosely connected into the physical products.

The main objective of the research is product data recognition for modular products in a PLM system. Objective is to give answers how to update data maintenance in the case company. The idea is to find suitable modeling methods that serve modular product families and to evaluate alternatives. Furthermore, the target of this research is to increase knowledge about the design requirements for the modular product documentation and data maintenance in the IT systems. The aim is to consider collaboration among IT systems. The research does not offer generalizable knowledge and the results primarily serve the case company.

As a result of this thesis it is intended to get analysis about concepts of modular product recognition in PLM system. This includes the proposed modeling techniques for the modular products. The guidelines for product structure management and the roles of IT systems leads to viable concepts to support modular product management.

The emphasis of the study is on Siemens Teamcenter and NX environments as these systems have the most users where the changes occur. ERP system is left outside of the scope because the configuration work is intended to move to other systems. For product structures in PLM the service product structures are not under discussion in this thesis. Consideration of architecture management tool is inadequate due to the author having limited access to the system during the study. Verifications for the modeling concepts are left outside of this research as the activities are not in a proper stage where evaluations can be established. Physical modular products are excluded from this research. The only physical entities are conveyor related examples to illustrate modeling methods. Due to the limited resources, the consideration is limited to mechanical interfaces.

The case company is going to deploy an architecture management tool for handling modular product assortment data. The research tries to reduce the gap of operation philosophy and data management practices between the architecture management tool, CAD (Computer-Aided Design), and both the software provider and case company. This mutual understanding about modular product's data management among the stakeholders is the objective for the case company.

The academic objectives of this case study define knowledge of other researchers about PLM-systems, modularization, configurable products, product structures and configurators. The objective can be fulfilled if modular products can be modeled to serve a modular product in a PLM environment and all the research questions are answered.

2.2 Research questions

The following research questions concretize the research objectives presented in Chapter 2.1:

1. What are the capabilities and restrictions of IT systems for modular modeling?
2. How is the product structure of a modular product in a PLM system stored?
3. How is maintenance of product data performed?
4. How is data flow from sales configurator to product individual improved?

All the research questions focus on the case company's objectives. By answering the first research question the study aims to describe available and suitable modeling methods for modular product family. The second question is taking into consideration the modular product structure that can be handled in PLM. The third question attempt to identify the future combination of IT systems to support modular product family data management. The fourth questions lead to the consideration of necessary changes for configurators to support modular product configuration.

3. STRUCTURE OF THE STUDY

The study is divided into two main parts. The first one includes a literature review where interesting topics for the case are discussed. The second part contains the case and results of this study.

The thesis begins by an introduction in Chapter 1 and a research description in Chapter 2. The research methods of the study are in Chapter 4. Chapter 5 contains the literature review which focuses on PLM systems, product structures, modularity definitions and modularization theories.

Chapter 6 presents the case company and includes the description of the case. The modeling methods are considered and tested by examples. The set of IT systems is discussed and a future scenario for it is created. Chapter 7 collects the key findings from the study. Chapter 8 includes the results of the study and answers to the research questions. Chapter 9 discusses the thesis and future researches. In Chapter 10 there is a conclusion about the thesis.

4. RESEARCH STRATEGY AND METHODS

This chapter describes the process of the study. It includes information about the exploited theory base. The implemented methods for the case study are introduced with research related parties.

There are three different main approaches for the academic research; qualitative, quantitative and mixed methods. In qualitative research the focus is on exploring the phenomenon that underlies the research. It can also be understanding of individuals and groups or focused on a social problem. A researcher makes interpretations of the data, and the written report structure is flexible. One instance of qualitative research is a case study. In a case study the researcher explores thoroughly a program, event, activity, process or individuals. Case studies are implemented under a certain amount of time and activity. (Creswell 2014)

In quantitative research the theories are tested by systematic empirical investigations and statistical observation of the phenomena. The final report of the quantitative research has more fixed structure compared to qualitative research with introduction, literature and theory, methods, results and discussion. Mixed methods research integrates elements from both qualitative and quantitative methods, and, integrates data from them. The assumption in mixed methods is that the separate use of a qualitative or a quantitative research is not as efficient as combining them. (Creswell 2014)

In this study the qualitative approach is chosen as the research divides into a literature review and a case study. The action study was considered for the research but due the early phase of the IT systems update process in the case company the proofs of change could not have provided. The first part of the literature review considers PLM system as a concept and its capabilities. In PLM systems the management of modular product structures and their visualizations are discussed. Sales configurators and product structure configurators are also presented.

The second part of the literature review focus on a modular product. It includes a modular product related definitions and modularization methods. In Chapter 5 the literature review is described in more detail. Figure 1 illustrates the research process and connects the topics into the research questions.

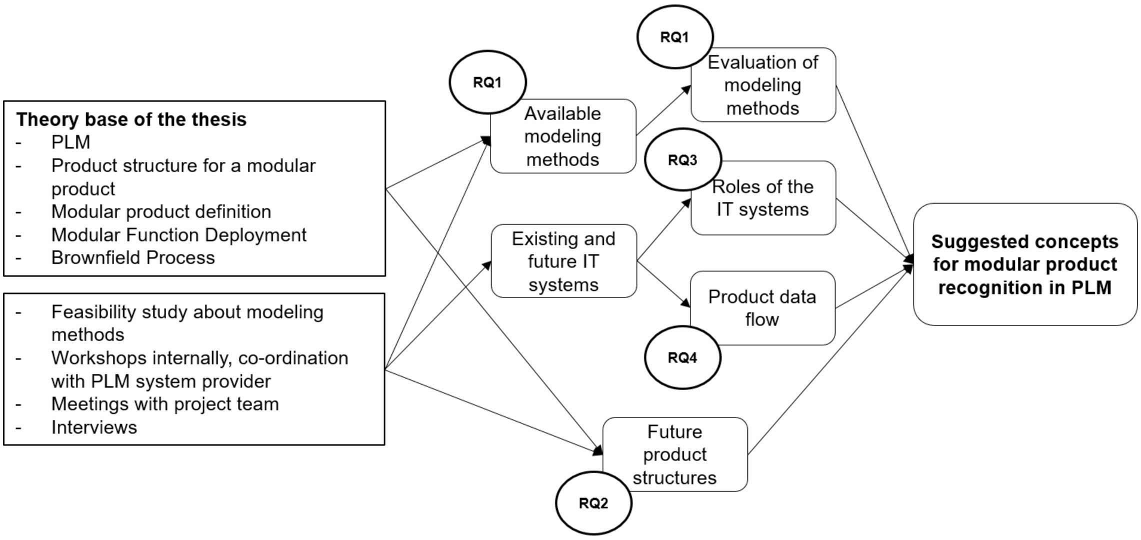


Figure 1. *Research process of the study*

For the case company a feasibility study about modeling methodologies proceeded by internal and cooperated workshops and by knowledge from internal databases. In addition to internal discussions by consultation the PLM system provider knowledge about practical solution methods and guidelines is gained. This includes meetings and workshops. The author gained information by reading documents, instructions and manuals provided internally and by the PLM system provider. The information about the study objects for the case company is collected by interviewing managers and experts. The existing and the future set of IT systems is considered by interviews and a workshop.

This chapter presents the research process of this study. It explains the reasons for the utilized methods. There are also considerations of the chosen structure of this thesis.

5. THEORETICAL BACKGROUND

The theory includes topics related to the modular product and its recognition in the IT systems. This chapter considers modular product structure creation. It also introduces theories that support modular product modeling, product data management and configuration work.

The purpose of a literature review is to locate and summarize the studies about a topic. There is no right or wrong way to implement a literature review. An established practice is to capture, evaluate and summarize the literature. Creswell's proposed way to proceed a literature review is defined in the following way:

1. Determine key words
2. Search for information by using the key words
3. First try to find around 50 research articles or books related to your topic
4. Go through the chosen articles or books and duplicate the ones that are on the focus of the research
5. Design a literature map (a visual picture) for grouping the literature topics and positioning the topics with the larger body of the research
6. Create draft summaries about the most relevant articles that will be combined into the final literature review
7. Structure the draft summaries into the literature by organizing it by important concepts

As mentioned earlier in Chapter 2.1 the chosen key words at the beginning were *modularization*, *configurable products*, *product structure*, *configurators* and *PLM-systems.* After going through the articles under these topics a literature map was created. A literature map is presented in Figure 2.

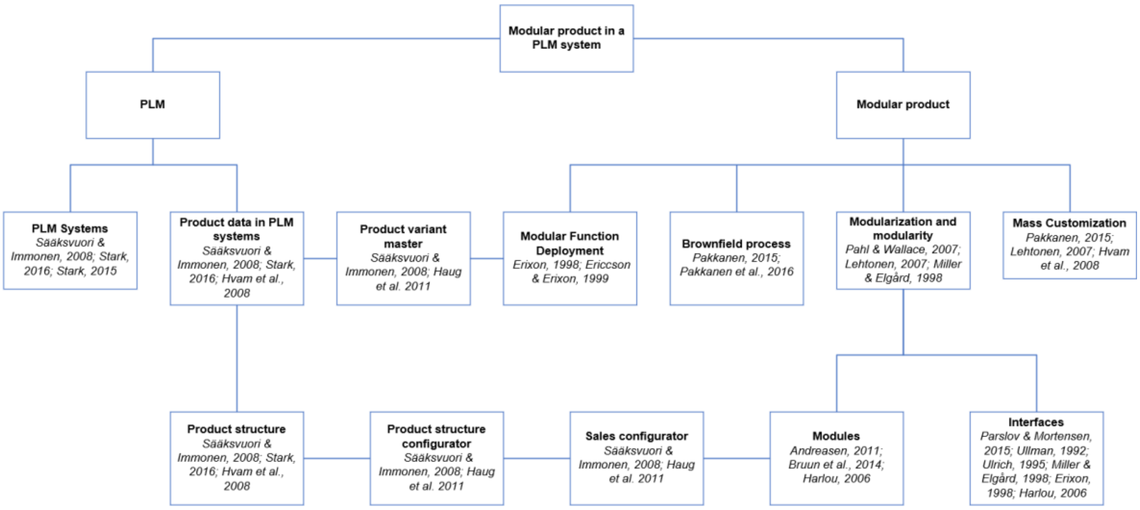


Figure 2. *A literature map of the research*

The topic of the thesis is divided into *PLM* and *Modular product*. All the sub-topics under these main topics were chosen as the main topics after literature search by using the presented key words.

As described in Chapter 2.1 the modular product data identification in the case company is in a very early phase. There are no modular products or product families under the scope of this research. Because of the early stage of the study and the experimental characteristics of the research the qualitative research approach was chosen. The author is a part of the team that is responsible of the modular product data management. The result is going to be a combination of scientific principles and practice. Therefore, a case study research was chosen as a research method for this study.

5.1 Product lifecycle management

Product lifecycle management (PLM) with its purposes and benefits is presented as follows. Concept and system characteristics of a PLM are examined. Product data management (PDM) and management of product structures in PLM environment are discussed. Customizable product structures are under special consideration. The Product variant master that is intended to be a tool for management of customizable product structures is presented.

5.1.1 PLM essentials

"Product Lifecycle Management is the business activity of managing, in the most effective way, a company's products all the way across their lifecycles; from the very first idea for a product all the way through until it is retired and disposed of" (Stark 2015, p. 1). (Sääksvuori & Immonen 2008, p. 3) states that product lifecycle management (PLM) is a concept that provides methods for controlling the product information. The focus is on handling the processes of creating, distributing and recording product related information from the initial idea of the product to the scrap yard according to (Sääksvuori & Immonen 2008, p. 9). The product's lifecycle in the general case is divided into five phases by (Stark 2015, p. 6). The lifecycle phases are illustrated in Figure 3.

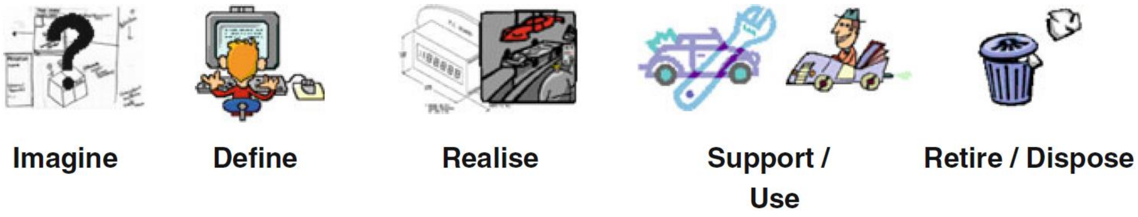


Figure 3. *Lifecycle phases (Stark 2015, p. 6)*

In the first phase the product is just the ideas in the designer's head. In the define phase ideas are converted into detailed form and the main functions are clear. In the end of the realise phase, the product has its final form and is ready to use as a commodity. In support/use phase, customers receive the value of the product. During this phase the product may need to be maintained and occasionally repaired. In the final phase the product is disposed from the customers' point of view and for the company the product is retired. (Stark 2015, pp. 6-7)

The objective is to preserve knowledge about products and methods used in the company. Without specific documentation the knowledge only stays in the minds of the employees. When PLM system is working properly for a company the latest and correct information is easily available without a delay for the people who have the prescribed data ownerships. These are crucial objects to achieve in the modern business world since the same information must be accessed in an extensive and scattered network of subcontractors and partners. (Sääksvuori & Immonen 2008, pp. 3, 5-6)

5.1.2 Why should a PLM system be implemented?

The reasons for deployment of a PLM system vary depending on the company. Variations are results of differences of the business fields between companies. Users need to understand what the system will achieve, before choosing and implementing a PLM system. Companies also have their own business strategies. Some companies are using PLM systems as a tool to achieve improvements on effectiveness of daily business. For some companies it is an investment and a key factor of the business strategy. (Sääksvuori & Immonen 2008, p. 24)

Nowadays manufacturing companies are facing new challenges as a result of outsourcing and continuously fragmenting value chain. All these changes had become possible by IT systems that support management of products in their different life phases (e.g. CAD, manufacturing and product management tools). Continuously increasing the amount of data and different IT systems can become an issue in companies. IT systems usually are not compatible with each other and the result is trapped data in their respective systems. PLM system is one tool to tackle these issues by combining data from different systems and managing accepted data formats. (Bruun et al. 2012, p. 1)

PLM systems are relatively new, and continuously improving. An increasing number of companies apply PLM systems, due to competition in the markets and demand for more complex and custom-tailored products and services. Complexity in products is increasing the need for research and development in the companies. It is also increasing the amount of design data. In many cases PLM system is a solution for data management. (Sääksvuori & Immonen 2008, p. 24)

The way of business is continuously developing. Companies are more and more specializing in narrowed fields of business. The amount of changed information is increasing between the companies as a result of outsourcing, sub-contracting, alliances, partnerships etc. These kind of practices of cooperation are known as network economy. Another aspect concerning changes in business is longer service contracts between companies. Many benefits are achieved by using specific information about existing products in all the phases of their lifecycle. (Sääksvuori & Immonen 2008, p. 25)

Deployment of PLM can reduce product-related costs. The costs related to material and energy consumption are fixed from the early phases in product development. PLM offers tools and knowledge to minimize these costs. Costs raised from recalls, warranty issues and recycling are also considered in PLM. (Stark 2015, p. 22)

Global competition is causing a need for faster production. 80-90 % of the required time to get a product to the market has been estimated to be product planning and development. If the company wants to achieve improvements on time to market, then the most efficient way is to tackle time consumption during the development phase. The improvements can be reached for example by deployment of Computer Integrated Manufacturing (CIM) and Concurrent Engineering (CE), in other words with the help of information technology. PLM systems are giving remarkable tools for this development. (Sääksvuori & Immonen 2008, pp. 24-25)

5.1.3 PLM concept

The product lifecycle management concept is a general plan for daily business in a company. It includes methods, processes, guidelines and instructions how to follow the rules. Applied concepts vary depending on the company but there are usually principles that concern at least the following topics:

- Terms, abbreviations and keywords used for defining products and lifecycle for the products
- Product information (data) models and product models
- Definitions of products and product-related information (items, structures, documents related to the products, definitions of product information, etc.)
- Practices of lifecycle management and principles applied in the company (information management principles for example versioning principles, information statuses, etc.)
- Processes related to product management (product information management processes)
- Instructions on how to apply the concept in daily work

The PLM concept is always unique for the specific company including detailed and ambitious objectives. The scope for PLM concept needs to be clear and detailed based on the strategy and business architecture of the company. A good PLM-concept continues to evolve according to the changes of the company's business and its requirements. (Sääksvuori & Immonen 2008, p. 11)

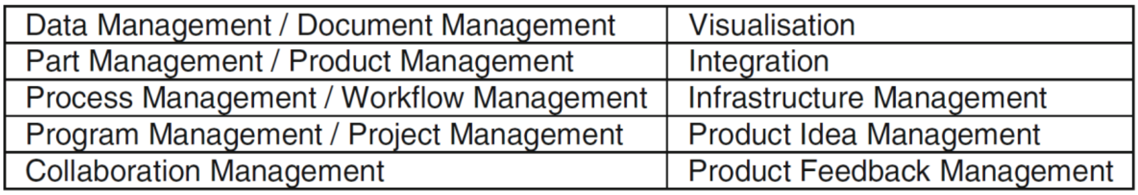
PLM concept is also directly related to the products lifecycle. Employees are trained to consider products from a lifecycle perspective. Meaning that in a very early phase of designing and manufacturing methods, disassembling and recycling are under consideration. The recycling specialists are aware of updates in environmental laws and keep personnel informed. Employees are encouraged to find ways to design reusable products and re-use parts in new products. Opportunities add value and create revenue across the product's lifecycle and connected to environment-friendly products, customized products, support and service offers and responsible business methods especially in low-cost countries. Before PLM, the departments of the company were scattered and usually the flow of information was insufficient. Deployment of PLM integrates information and making employees think about the entire lifecycle of each product. (Stark 2015, pp. 15-16)

5.1.4 PLM information systems

Management of activities in PLM is a wide and cross-organizational task. It needs organization and co-ordination between resources and tasks. Decisions, objectives and results need to be controlled. A product or a service needs to be managed in its all lifecycle phases described in Chapter 5.1.1. (Stark 2018, p. 14)

At the principle level PLM system is a combination of applications and the system's applications that can be divided into categories of generic applications or specific applications. These principle level generic applications can be found in any companies and all kinds of products. For example, "data management" application is needed by a design engineer in ship building industry and data management also is needed by a project manager in the pharmaceutical industry. (Stark 2015, p. 176)

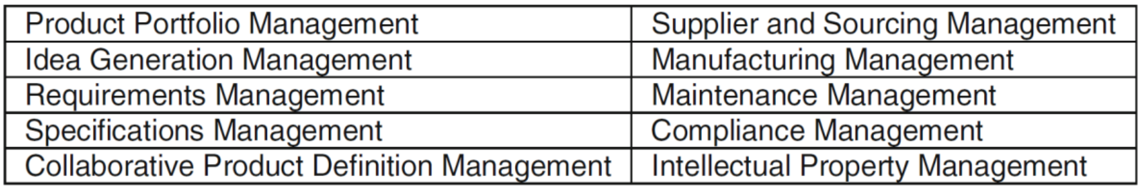
All the company's PLM functions should be managed in the PLM applications. Figure 4 shows an example of generic applications by Stark.



Data Management / Document Management	Visualisation
Part Management / Product Management	Integration
Process Management / Workflow Management	Infrastructure Management
Program Management / Project Management	Product Idea Management
Collaboration Management	Product Feedback Management

Figure 4. *Generic PLM applications (Stark, 2015, p. 177)*

Generic PLM applications are applied in any company in one way or another. All these generic applications are used by most of the employees in a company that have product-related activities. Figure 5 shows an example of specific applications.



Product Portfolio Management	Supplier and Sourcing Management
Idea Generation Management	Manufacturing Management
Requirements Management	Maintenance Management
Specifications Management	Compliance Management
Collaborative Product Definition Management	Intellectual Property Management

Figure 5. *Specific PLM applications (Stark 2015, p. 178)*

Specific PLM applications are more detailed and the use for them is done by few employees in the companies. PLM applications at more practical levels are described in the following sections. (Stark 2015, pp. 176-178).

5.1.5 PLM systems

On an ideal level, the PLM is an information processing system or set of IT systems that combine all the functions of the company (Sääksvuori & Immonen 2008, p. 13). In practice applied systems in companies usually only consists of a couple of business functions (e.g. product design and development) (Sääksvuori & Immonen 2008, p. 13). PLM system integration is implemented by systematically connecting company's business processes and product data concerning products under development and the produced products (Sääksvuori & Immonen 2008, p. 13). Figure 6 shows the internal PLM system's possible functions:

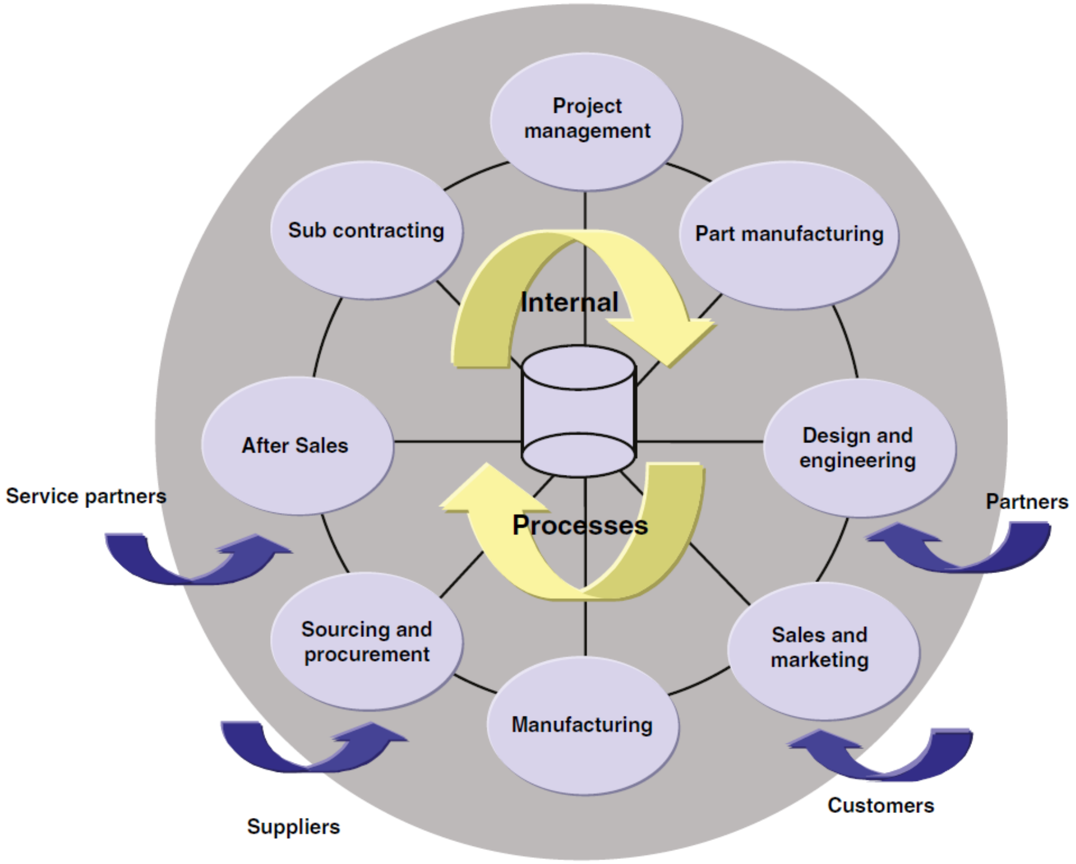


Figure 6. PLM system's functions (Sääksvuori & Immonen 2008, p. 14)

As can be seen in Figure 6 company's functions have traditionally been separated islets in the company and they have managed data in their own systems(Sääksvuori & Immonen 2008, p. 13). Fragmented data and different IT systems cause unnecessary workload to the whole internal process (Sääksvuori & Immonen 2008, p. 13). In this research the focus is to achieve principles and common practices for design engineering work concerning data recognition of modular product data. The implementation of IT systems in practice is discussed in Chapter 6.6

5.1.6 Product data in PLM systems

PLM systems have many functions to perform. In this section the typical functions of the systems are introduced and shown how functions are implemented on a practical level. Each of these functions need to work properly in order to gain all the advantages from a PLM system.

The PLM system usually manages the statuses of items. The PLM system automatically controls creation of new files and updates existing ones. One way to execute these actions is through check-out and check-in procedures. Checking-out an item marks it as under revision. During check-out the item is locked so that other users are unable make changes to the item. Before check-out, the PLM system checks the editor's privileges for editing the item in question. When the changes are complete, the designer checks-in the item to execute the changes and release the item. After check-in the item is no longer locked, and other users can check-out the item for additional changes. (Sääksvuori & Immonen 2008, p. 27)

For creating an item, rules are necessary to specify attributes needed for describing the item. Attribute information can be divided into three categories: individual product-based information such as serial number of a component, generic information which is connected to the item's position in the hierarchy of the product structure and user specific information as remarks and notes. (Sääksvuori & Immonen 2008, p. 32)

In the manufacturing industry field, a specific workflow usually is applied for creating a new item. The designer prepares needed information for the item such as drawings or other necessary documents. After the necessary data is attached into the item, senior designer reviews it. After possible corrections, the department manager accepts the document. After the item is accepted, it is sent or released for distribution. To avoid unnecessarily large quantity of items, a revisioning procedure is applied. This means that when some changes need to be applied for some item, it is revised instead of creating a new item.

The PLM system handles names of the revisions, usually by number (0, 1, 2, etc.) or a letter mark (A, B, C, etc.) to define the different revisions about of the same item. The PLM system also offers the latest revision of the item for the applications linked into PLM. Typically, only accepted and released items are recorded into the PLM system. The PLM system also stores logs of events performed on items. For example, these events include viewing, copying, changing, commenting or printing the item. The PLM system also records Engineering Change Requests (ECRs) and Engineering Change Orders (ECOs). ECRs and ECOs are discussed more specifically later in this chapter. (Sääksvuori & Immonen 2008, p. 28)

Retrieval is one of the most important functions in PLM systems. Time used for searching products does not provide any value. According to studies, engineers use up to 80 % of their time on administrative and retrieval activities. After finding data, there may be issues concerning permissions to access the data, or the data may be obsolete. (Stark 2016, p. 162)

Information searches are made possible by attributes of the items. Attributes describe items in the most efficient way so users of the systems can reach the data and be sure it is correct and up to date. With attributes the system user can delimit the searches concerning to same classification of data. Efficiently working retrieval activities in addition to decreased time consumption on searches the activities are also decreasing the amount of design data. When the designer finds existing data there is no need for creating new items. Often it is quicker to create a new item compared to search for an existing one. This is a typical situation especially in large companies. By using more specific metadata, searching for data becomes easier. On the other hand, overly specific applied metadata increases the workload during establishment of items. (Sääksvuori & Immonen 2008, pp. 29-30)

Change management is needed for products to keep on track about the changes and reasons the changes have been implemented. Everybody wants the latest and correct information. Most companies have many products, main assemblies, sub-assemblies, components, raw materials, processes, product data, documents. There can be a lot of data which changes daily. Data changes mean management of changes. (Stark 2016, p. 107)

Change management is a tool which is usually integrated into the PLM system. It contains the latest information about changes, as version changes to a product or a component, revision changes in documents or items. After updates change management ensures that the latest data is available in the right place and the right time. (Sääksvuori & Immonen 2008, p. 16)

Change management in the PLM systems is typically performed by ECRs and ECOs. They allow a smooth and proper authorization to the change processes without interruptions to production. When ECRs and ECOs are used efficiently problems concerning the possible issue on usage of obsolete data is eliminated. (Stark 2016, p. 107)

Change process starts by creating an ECR or in some cases straight by creating an ECO. ECRs are requests for changes. Requests might be for example, results of mistakes in design, customer demands or suggested improvements. Usually engineers handle the ECRs so they need to estimate how to proceed with necessary changes. The person that defines the ECR needs to describe the problem or solution idea clearly. Attachments included into ECR (e.g. photos, CAD data, etc) is an efficient way to illustrate the case. The person needs to define the subjects of the change (items, documents, methods, etc.) affected by the suggested change and explain the reasons for the change needed. Completed ECR is delivered to the persons who are responsible for the changes according the workflow defined by the system. After ECR delivery possible negotiations can be proceed concerning to the ECR between the ECR creator and receiver for example by email. (Sääksvuori & Immonen 2008, p. 34)

When the people responsible for the requested changes are certain about the actions, then an ECO is established. An ECO can be based on the earlier ECR or ECO and can be created without any change requests (ECR). The benefit of ECO is that large number of ECRs can be bundled up into one ECO even if the ECRs are produced globally. This accelerates the approval procedures for the changes. More flexible approval process enables companies to react quickly in different kinds of situations. After the ECO is ready and verified by those responsible, the updates for the items or documents can be released. After the changes are released, interested parties are notified. This is implemented by Engineering Change Note (ECN) which is usually based from ECO.
(Sääksvuori & Immonen 2008, p. 34)

5.1.7 Product structure

For an efficient PLM system, it is essential that items and their classification are uniform within each company. Another key factor is that items form separate classes, subclasses and groups at a suitable level of coarseness. These levels should follow the company's rules and standards. It is important to consider the level of coarseness. Too detailed classifications will slow operational processes and increase the amount of item maintenance work. For this reason, the suitable level of precision needs to be defined beforehand. The item hierarchy and its structure need to be documented. (Sääksvuori & Immonen 2008, pp. 12, 32)

The management and maintenance of product structures is one of the most important tasks of the whole PLM system. Product structure provides the basis for many other basic functions in the system. In many cases properties such as version management, structural presentation of information, change management and configuration management are based on the product structure. PLM systems usually have a feature that enables filtering the product structures so that certain parts of the structure are emphasized while others are hidden. The filtering is useful when the product structure is large and complex. (Sääksvuori & Immonen 2008, p. 30)

During the product's lifecycle many kinds of people get involved with information that is directly or indirectly connected to the structure of the product (e.g. salespeople, customers, recyclers). Usually required data form regarding product structure varies among these groups. Some users need just a simple list of items, but others can find it useful if the items are structured somehow. A structure with more dimensions contributes meanings for items. Hierarchical structures are usually used to model the components of a product. When the product structures are under establishment all the stakeholders need to be under consideration. (Stark 2016, p.138)

One common applied hierarchical structure is a Bill of Materials (BOM). Figure 7 shows an example of BOM by Stark:

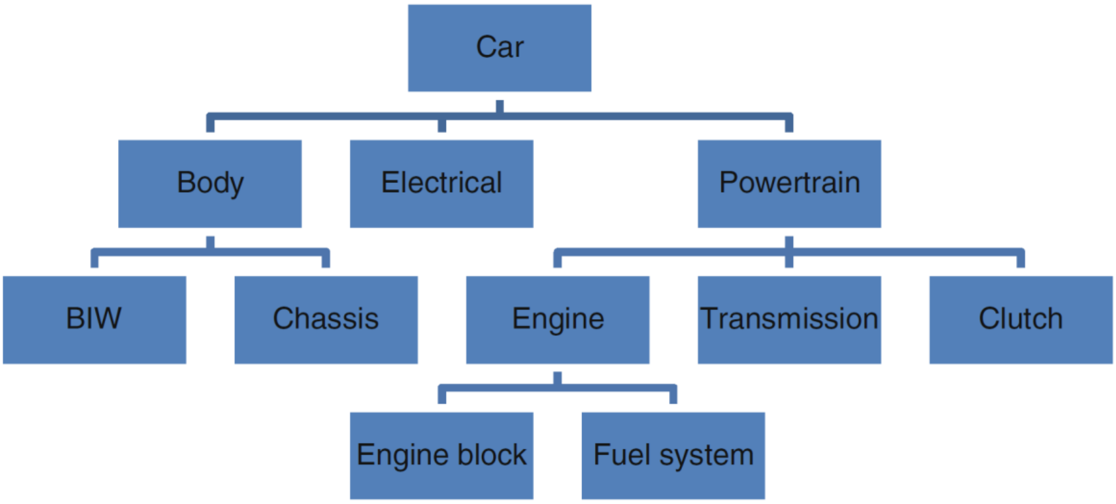


Figure 7. *An example BOM of a car (Stark 2016, p. 139)*

The same information which is described in Figure 7 also can be structured in array form. There can be different kinds of BOMs about the same product. Popular applied BOMs are the Engineering Bill of Materials (eBOM) or (EBOM) and the Manufacturing Bill of Materials (mBOM) or (MBOM). These are BOMs that make up the end item from a design viewpoint and from a manufacturing viewpoint respectively. For example, there might be additionally needed machine oil in a mBOM but it is not included in an eBOM. Figure 8 illustrates an eBOM. (Stark 2016, pp. 139-140)

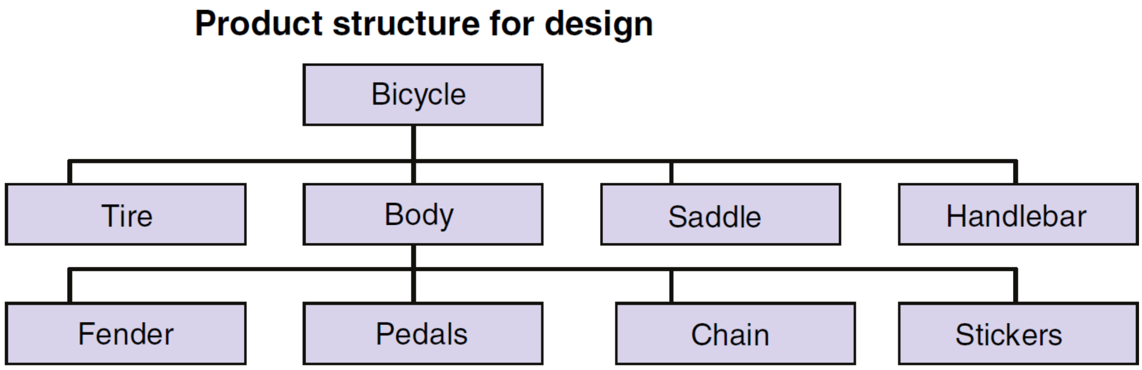


Figure 8. *An example of an eBOM (Sääksvuori & Immonen 2008, p. 31)*

In Figure 9 there is an illustration of mBOM example.

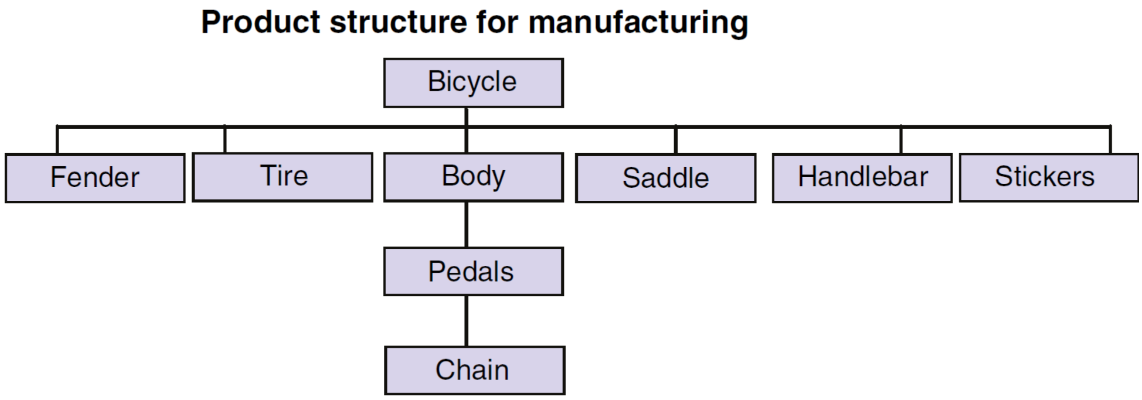


Figure 9. *An example of a mBOM (Sääksvuori & Immonen 2008, p. 31)*

Modern PLM systems can handle several product structures of the same product. Maintenance for many product structures is not an easy task so the choices for applied product structures need to be under careful consideration. The product structure may consist of functional modules, of individual parts or subsections and assemblies depend on the precision level of the description. (Sääksvuori & Immonen 2008, p. 32)

5.1.8 Customizable product structure

Customizable products are usually manufactured and assembled by utilizing configurable modules (see Chapter 5.2.3), entities and characteristics according to the wishes of customers (Sääksvuori & Immonen 2008, p. 46). Companies tries to gain the benefits of mass customization (Chapter 5.2.2) to produce variable products with high capacity. By customizable products a company can achieve products with thousands of different variations without engineered-to-order (ETO) designing. In Figure 10 there is an example of the configuration process (Sääksvuori & Immonen 2008, p. 62).

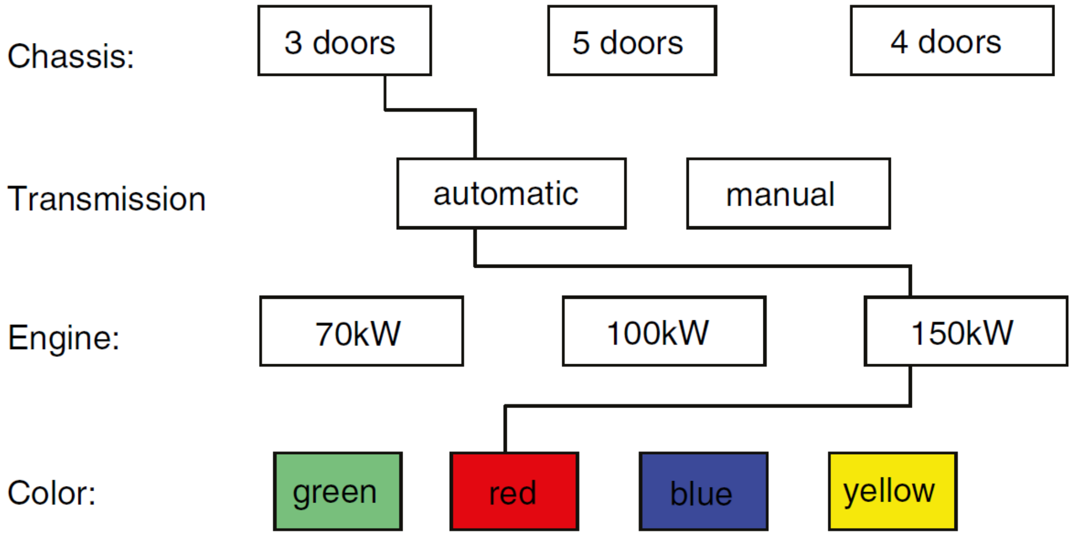


Figure 10. *Configuration example of a variable product according to (Sääksvuori & Immonen 2008, p. 62).*

The example is roughly simplified but if all different combinations are allowed there are 72 different product structures as a result of configuration by given options (Sääksvuori & Immonen 2008, p. 63). It is obvious that managing unique product structures for all different variations is nearly impossible and an enormous task. That is why there is a need for customizable product structures.

There are a lot of different ways to describe a product structure that is configured according to customer wishes (Sääksvuori & Immonen 2008, p. 50) One approach to manage customizable product structures is to create a generic product structure that includes all the variations in a product family on a general level.

5.1.9 Sales configurator

A sales configurator is intended to manage sales properties of the product and the rules connected to the sales properties (Sääksvuori & Immonen 2008, p. 62). The rules define the accepted sale combinations and prevent the forbidden combinations. For example, the company wants to restrict product options that they do not offer a coupé car with a diesel engine (Sääksvuori & Immonen 2008, p. 62). Sales configurator can also handle an information needed in sales, for example customer related price lists of the sales properties or market area information (Sääksvuori & Immonen 2008, p. 62).

In the sales configurator a so-called sales structure is created. An example of a sales structure is illustrated in Figure 10. Sales configurator can be a separate application or integrated into PLM system. When sales configurator is integrated in PLM the product structure can be created in the PLM with the items and item variations that correspond the properties defined in the sales configuration. This requires that the PLM system is supporting configuration for the product structures. (Sääksvuori & Immonen 2008, pp. 62-63)

5.1.10 Product structure configurator

A product structure configurator can be part of the PLM system or it can be a separate application that is integrated into the PLM system. A product structure configurator receives the sales configuration as an input value. A product structure configurator creates the fully configured product structure as an output value that matches the sales configuration. Managing the product structure in the product structure configurator is a challenging task due to the fact that the amount of variant product structures can easily rise to tens of thousands (or hundreds of thousands) different structures. Therefore, a product structure configurator requires a carefully planned product model that corresponds the sales features and the physical item structures. The structure configuration application also needs to have a sophisticated user interface to maintain the product model. In practice most of the commercial PLM systems are not supporting product structure configuration that well yet. (Sääksvuori & Immonen 2008, p. 63)

Another division of configurators besides sales configurator and product structure configurator is a configurator for mass produced products and a configurator for ETO products. Mass produced products have little complexity and there is usually no need for a complex product structure configurator. Engineered products have more complexity and the product structure configurators for them can consist of thousands of rules for combining product elements. This implies that the achievable benefits from them are more crucial for engineered products. By configurators a company can for example, get shortened lead times, improve product specifications quality, preserve knowledge, shorter time to specify products, optimize products, minimized routine work, higher quality deliveries and less needed trainings for new employees. (Haug et al. 2011, p. 197)

Lead times are one of the most important factors in a tightening competition (Haug et al. 2011, p. 197). Shorter lead times are also mentioned as a major advantage of the product structure configurators (Haug et al. 2011, p. 197). Main reason for shorter lead times is automated work instead of human expert work in sales and design processes (Haug et al. 2011, p. 197). Of course, savings in working hours are achieved due to the automated work (Haug et al. 2011, p. 205). Engineering companies that succeed in configuration creation process will achieve significant benefits (Haug et al. 2011, p. 205). Still implementation projects for configurators are risky and a project can be too cost demanding even if 90 % reduction of lead times and man-hours can be achieved (Haug et al. 2011, p. 205). Configurators demand continuous updates when the product assortment changes therefore high maintenance costs can emerge (Haug et al. 2011, p. 205).

5.1.11 Product variant master

Companies product assortment is usually large in industry and there are a lot of different product variants as a result of various customer wishes. To achieve an illustration of the products the product range is decomposed into so-called product variant master (PVM). An example of PVM is in Figure 11 and the general representation of a PVM is illustrated in Figure 12. (Hvam et al. 2008, p. 60)

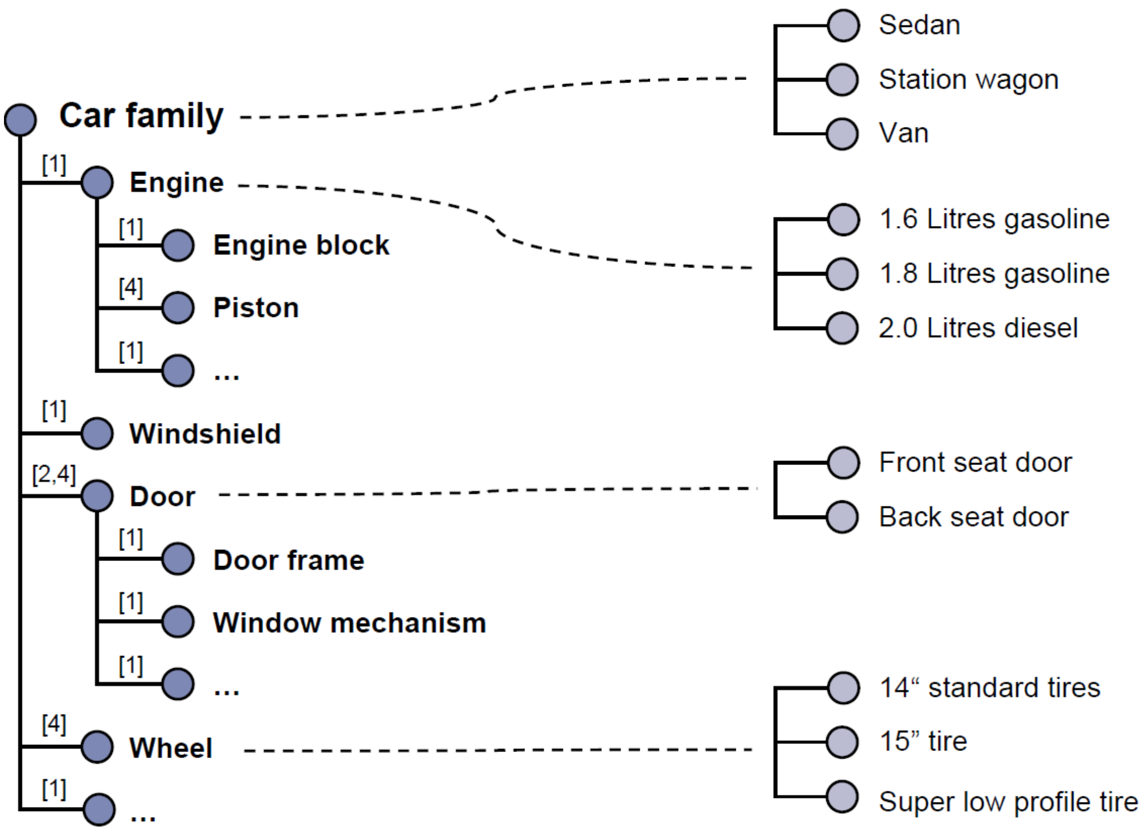


Figure 11. *An example of a product variant master that describes three car families, a general (part-of) structure on the left and a variation (kind-of) structure on the right (Harlou 2006, p.110)*

Generalization/Specialization structure in Figure 12 (in parenthesis on top right) includes common attributes and methods in modules and parts. The main difference between generalization and aggregation structures is that in generalization/specialization structure the modules and parts always inherit attributes and methods from the upper levels of the structure. For example, there can be a module for a car that is the generalization. The car module contains general attributes and methods for the car e.g. registration number and motor capacity. The module *lorry* is a specialization of the *car* module and *lorry* includes specific attributes and methods for lorries, such as maximum load or platform structure. (Hvam et al. 2008, p. 66)

Aggregation structure type in Figure 12 (in parenthesis on top left) includes object classes (modules and parts in this case) that together make up a whole for example, the parts of a car. In the aggregation structure relationships between modules and parts are described by quantities as specifying of the number of objects at each for example, four wheels in a car. In the aggregation structure modules and parts do not automatically inherit attributes between the structure levels. (Hvam et al. 2008, p. 67)

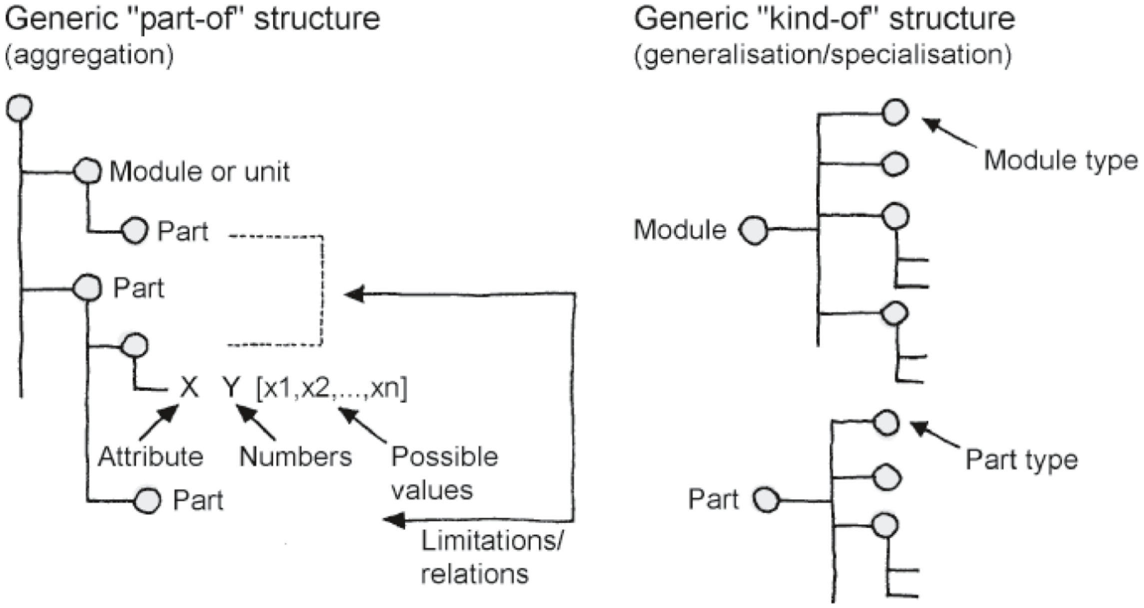


Figure 12. *General representation of a Product variant master according to (Hvam et al. 2008, p. 60).*

In Figure 12 the PVM has two parts. On the left side there is a generic structure (known as the part-of structure) which represents the product structure that contains all the modules and parts that can be found among the whole product family. For example, if the product family is a car every car has wheels, motor, brake system, etc. and those can be marked in the generic structure. Into the general structure some additional information can be included to describe more characteristics of the product family. Attributes define the different kinds of options for the general module or part. The general product structure related data (attributes, numbers, possible values and limitations/relations) is described in Figure 13. (Hvam et al. 2008, p. 60)

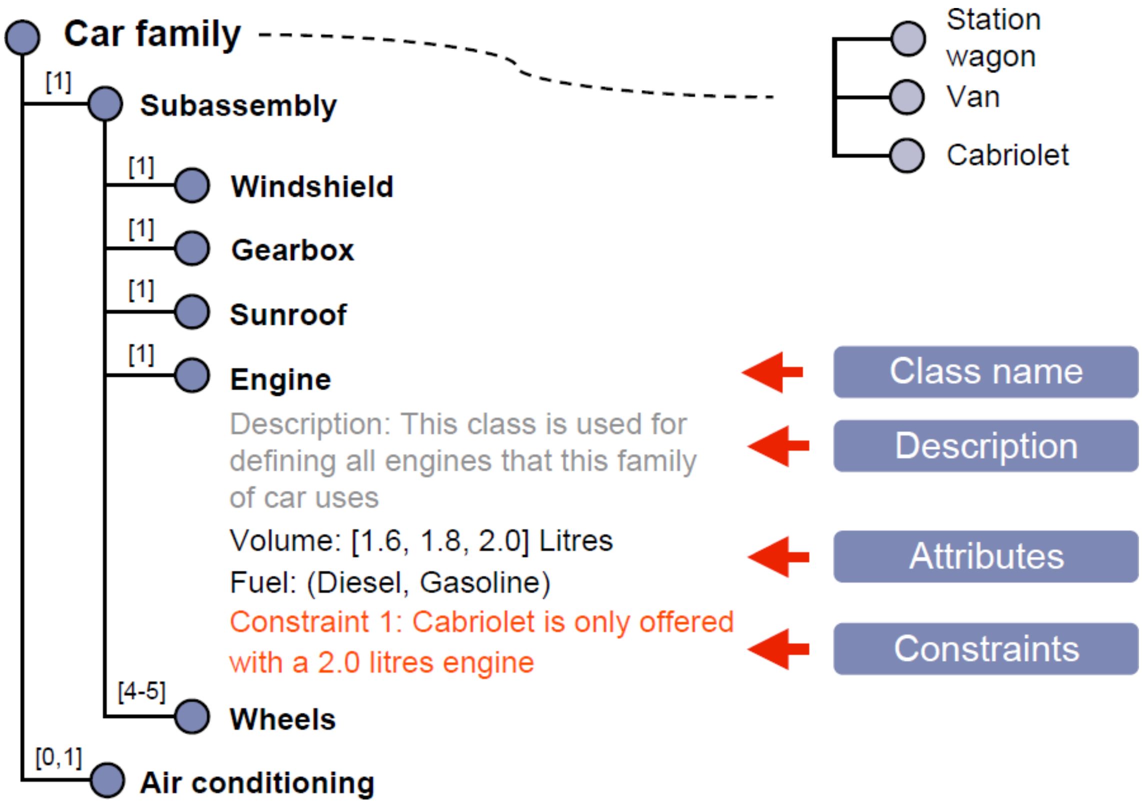


Figure 13. *An example of detailed information representations in a generic (part-of) structure of a product variant master according to (Harlou 2006, p. 111)*

As can be seen in Figure 13 all the modules and parts are defined by a unique name and there are the possible quantities for each (one engine and four or five wheels in this example). The names of the modules and parts need to be unique to avoid misunderstandings. The length of the names should be relatively short to keep the structure simple. The purpose of the description is to explain more information about the modules and parts. (Harlou 2006, p.111)

Attributes (in Figure 13) include all the offered variables among the module or the part. These variables might be color, mass, price, serial number, etc. There are four types of data formats supported in the product variant master for the attributes:

- *Identifier* is recognized as a text string, for example transmission of a car (Manual, Automatic).
- *Integer* is a whole number. In other words, integer can be positive, negative or zero (…, -2, -1, 0, 1, 2, …). The allowed expressions for the integer are a number, e.g. “[3]”, interval e.g. “[3-9]” or a fixed set of numbers e.g. “[3,7,9]”.
- *Real* is any rational or irrational number. The allowed expressions for the attribute type of real are a number, e.g. “[2.3]”, interval e.g. “[2.3 ... 3.7]” or a set of numbers e.g. “[2.3, 3.7, 9.6]”.
- *Boolean* is based on the nature of being “True” or “False”. For example, the existence of a hard drive (True, False).

The attributes are an efficient way to clarify a module or a part, as can be seen in Figure 13. For example, a declaration could be “Length [100 - 400] [mm]”. Length is the name of the attribute, [100 – 400] is the value interval and [mm] is the measurement unit. (Harlou 2006, p.113)

The objective in configuration is to achieve extensive product assortment. Usually there are some limitations for combining the modules and parts. In some cases, it is not reasonable to provide an excessive number of variations in the final products. Constraints (in Figure 13) are the rules to manage allowed combinations among the attributes. Constraints define how the modules and parts can or cannot be combined. Four different ways to utilize constraints are recognized in the product variant master:

- *Verbal* is a constraint that is in the form of one or more sentences, for example ”An open sports car cannot have a sunroof”.
- *Logic* is an efficient constraint for explaining complex configuration problems with few constraints, for example “Sports_car -> NOT sunroof”.
- *Calculation* is a constraint that is represented by math equations, for example “Car_weight = Chassis_weight + Engine_weight”
- *Combination table* can be used to illustrate constraints. The combination table shows how modules and parts can be combined.

The constraints are always marked under the modules or parts in the structure, even if the constraint appears in several modules and parts. Unique numbers or names are applied for constraints for identification. (Harlou 2006, pp.113-114)

In the product variant master in Figure 12 on the right side (known as the kind-of structure) describes all the available variants in the product family. The relationship between generic (part-of) and variant (kind-of) structures is called sub-kinds and super-kinds. The definition for sub-kinds and super-kinds is illustrated in Figure 14.

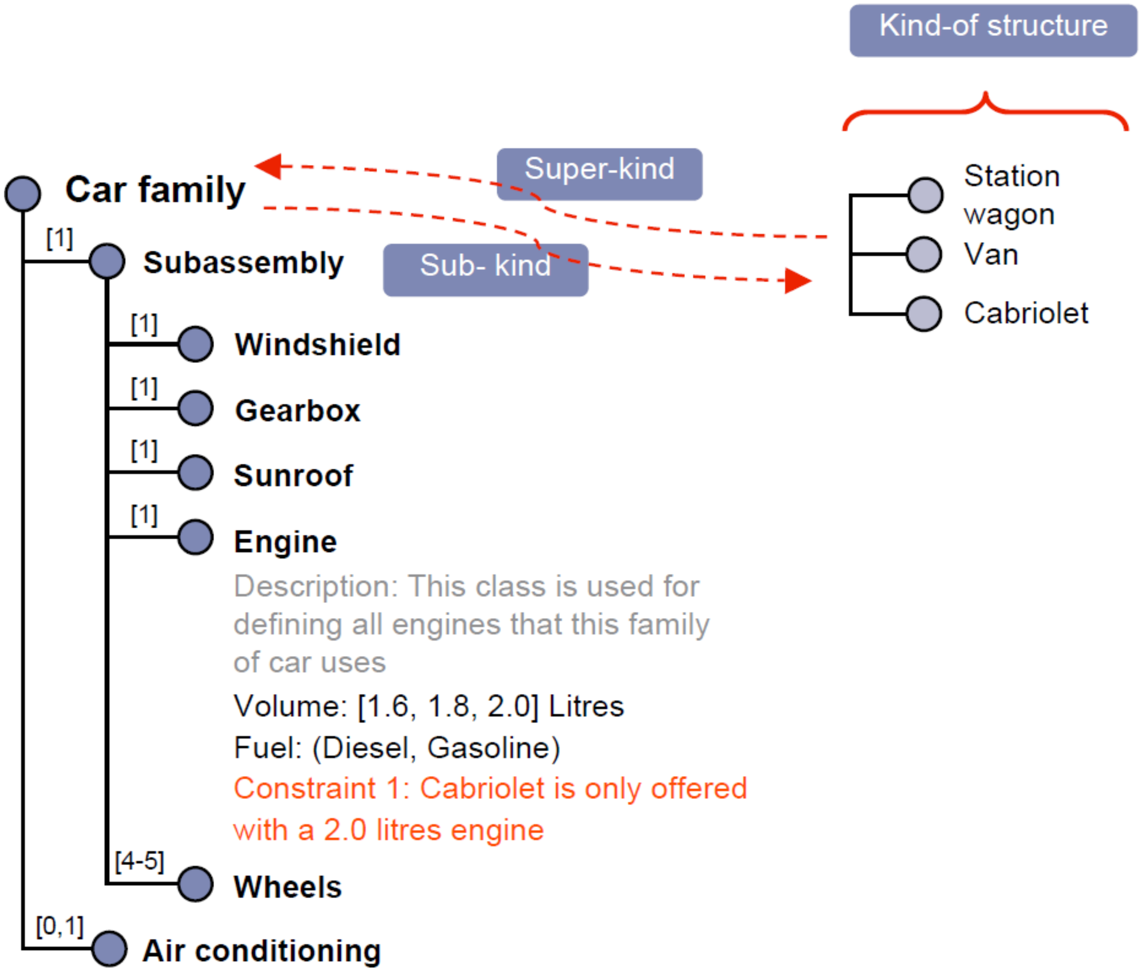


Figure 14. *A relation between generic (part-of) and variant (kind-of) structures (Harlou 2006, p.112).*

Variant (kind-of) structure describes the variation range in a specific class, for example in Figure 14 there is three options in the car family (Station wagon, Van and Cabriolet). (Hvam et al. 2008, pp. 152, 154)

5.1.12 Visual product models

Modularity makes products more complex and nowadays IT-tools are more sophisticated and enable management of product data efficiently in more detailed level. Development of a modular product architecture is a challenging job. Visual model is a way to ease the work and share ideas efficiently.

There is always some kind of product model which determines the decomposition and sequence of parts (Bruun et al. 2014). Product models have either a structural or functional point of view (Bruun et al. 2014). When modeling functions of a product the definition stays relatively on an abstract level (Bruun et al. 2014). The basis for functional models is on the flow of information, material or energy (Bruun et al. 2014). Functional flow diagrams can be useful to reveal functional modularity but for consideration of physical parts and their interactional relations it is not efficient (Bruun et al. 2014). Structural product models in Chapter 5.1.7 focus on attachments, hierarchy and geometrical relations between parts (Bruun et al. 2014).

According to (Bruun et al. 2014) it is mandatory to use explicit and visual models based on decisions concerning product modularity when the products are complex. They also assume that the models which offer several aspects of a product system, enable better decisions concerning the design of modules (Chapter 5.2.3) and interfaces (Chapter 5.2.4) between them. (Bruun et al. 2012) represents an architecture modeling tool for supporting communication and forming the basis for developing and maintaining modularity in product structures. The focus on description of architecture modelling is in a visual architecture representation (Bruun et al. 2012). (Bruun et al. 2015) divide a product into four different structures; system structure, module structure, interface structure and design structure.

By visual models the complexity becomes manageable and the project teams can achieve a shared and precise product system definition (Bruun et al. 2014). There are common characteristics for the systems, one or more of the following by (Bruun et al. 2014):

- A system delivers important functionality (braking, steering, loading etc.).
- A system is complex or includes new technology (hydraulics, cooling etc.).
- A system is aligned with an organizational structure and/or is affecting organisational structure.

Among system and modular point of views system perspective determines, it deals with the main functions of the product and takes into consideration the lifecycle phases of the product (Bruun et al. 2012). A system is a part of a product which realises its function and carries its properties (Bruun et al. 2015). Systems fall into groups by their functional identities which can be related to lifecycle or they can be aligned with an organizational structure according to (Bruun et al. 2015). There is an example of a product division by systems in Figure 15.

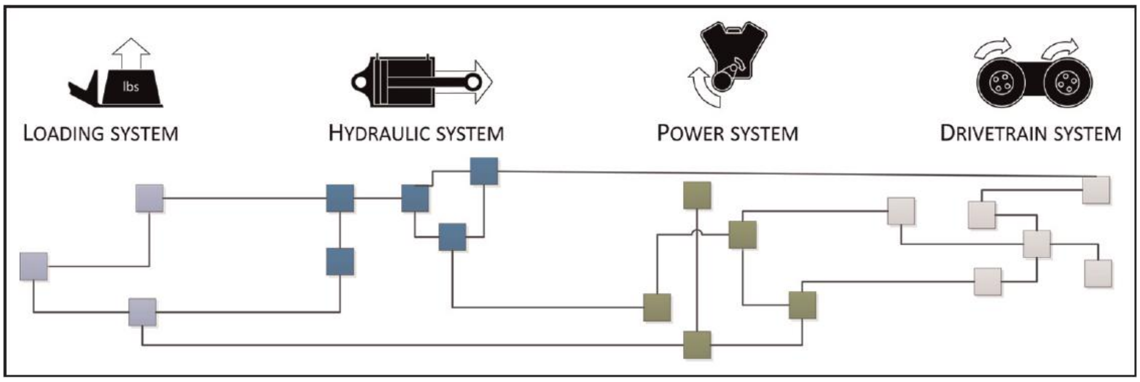


Figure 15. *Product division by systems (Bruun et al. 2014)*

Shown in Figure 15 are coloured boxes that represent components and the lines between components represent interfaces. The system structure is overloaded which means that the same components can be associated with multiple systems (Bruun et al. 2015).

Modular perspective divides the systems into parts of the whole and they are physically joined and encapsulated into modules with simple interfaces (Bruun et al. 2012). For managing interface there is clearly defined which system has the responsibility of the interface (Bruun et al. 2013). A component can be part of multiple systems, but the component is physically only in one module (Bruun et al. 2014). In practice this means that the module structure is so called 100 % BOM where all the product components are recognized once, and only once. Figure 16 shows an example of a product division by modules.

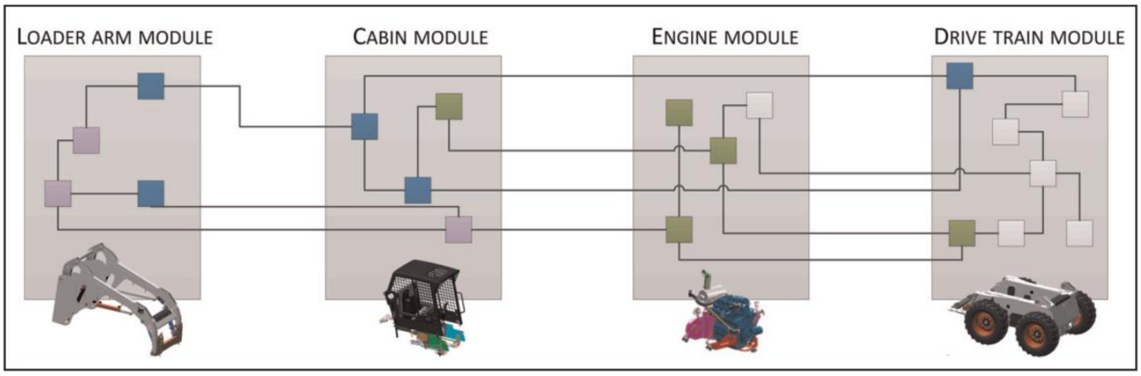


Figure 16. *Product division by modules (Bruun et al. 2014)*

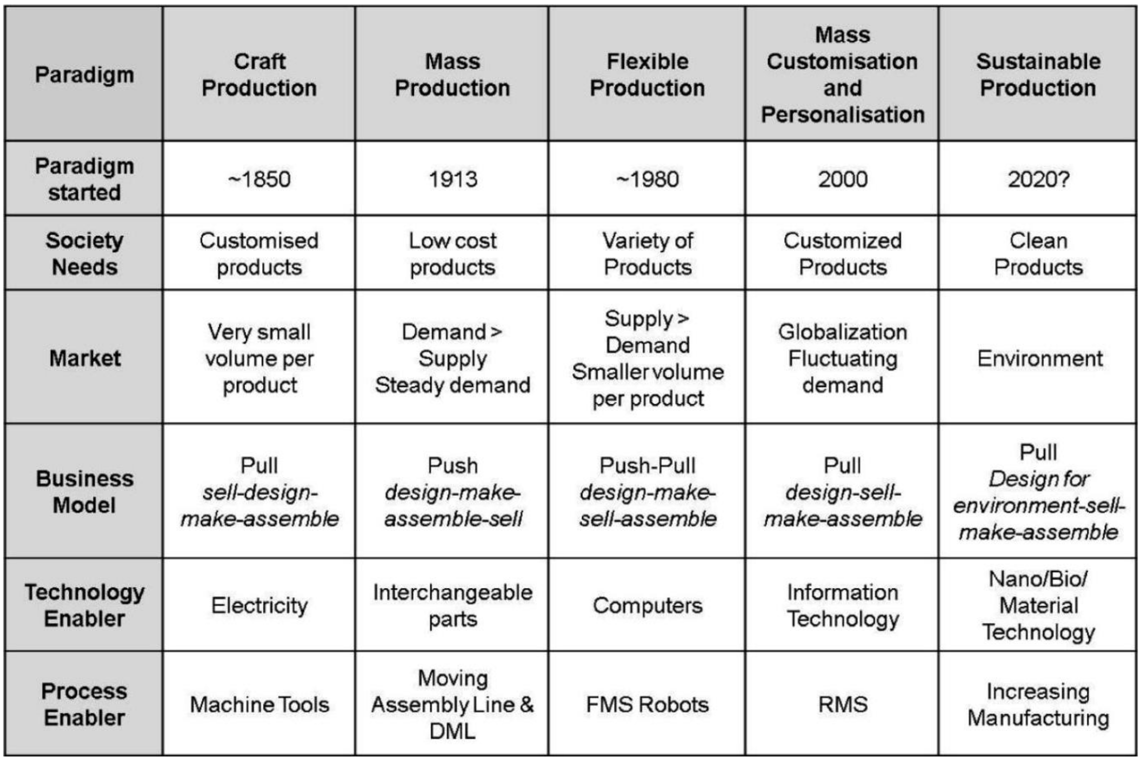
Functionalities of the product are physically realized in modules (Bruun et al. 2014). The module creation basis is on module drivers that are defined in Chapter 5.3.3 (Bruun et al. 2014). Module creation should support the best functionality of the whole product system and not only the aim to the best physical arrangement of components (Bruun et al. 2014). In practice the visual models can be create by office tools for example such as Visio or PowerPoint.

5.2 Modular product

The evolution of production methods is described in the following. Definitions for modules, interfaces, modularization and modularity are discussed. Modular function deployment (MFD) is examined as it is the background basis for the architecture management tool. The Brownfield Process that is a relatively new modular development method is also introduced.

5.2.1 Developments on production methods

Demand in the markets is evolving and competition between companies is tightening. Customized products have been traditionally connected into craftwork or engineered-to-order (ETO) products. Mass production lowered the demand for customer tailored products for a while but nowadays by mass customization more configurable products are possible to be produced with reasonable costs. In Figure 17 are the drivers for production paradigms development.



Paradigm	Craft Production	Mass Production	Flexible Production	Mass Customisation and Personalisation	Sustainable Production
Paradigm started	~1850	1913	~1980	2000	2020?
Society Needs	Customised products	Low cost products	Variety of Products	Customized Products	Clean Products
Market	Very small volume per product	Demand > Supply Steady demand	Supply > Demand Smaller volume per product	Globalization Fluctuating demand	Environment
Business Model	Pull *sell-design-make-assemble*	Push *design-make-assemble-sell*	Push-Pull *design-make-sell-assemble*	Pull *design-sell-make-assemble*	Pull *Design for environment-sell-make-assemble*
Technology Enabler	Electricity	Interchangeable parts	Computers	Information Technology	Nano/Bio/ Material Technology
Process Enabler	Machine Tools	Moving Assembly Line & DML	FMS Robots	RMS	Increasing Manufacturing

Figure 17. *Production paradigms (Jovane et al. 2003, according to Pakkanen 2015, p. 15)*

Abbreviations shown in Figure 17 are Dedicated Machining Line (DML), Flexible Manufacturing Systems (FMS) and Reconfigurable Manufacturing Systems (RMS). As can be seen in Figure 17 the demand for customized and environment friendly products is increased. Mass production partly will be replaced by flexible production, mass customization and sustainable production. The driver for the change is a result by combination of developments in manufacturing industry and in the society’s needs. (Pakkanen 2015, pp. 14-15)

According to (Duguay et al. 1997) flexibility in industry is the capacity to deploy or redeploy production resources efficiently and quickly to meet the requirements from the environment. (Duguay et al. 1997) emphasize that flexibility is one of the basic required characteristics in any production process. (Duguay et al. 1997) explain that there are different types of flexibility to adapt to changes (e.g. varying demand, changing technology, seasonally produced raw materials, uncontrollable lead times from suppliers, breakdowns, absenteeism etc).

5.2.2 Mass customization

(Victor & Boynton 1998, according to Pakkanen 2015, p. 18) state that at some point existing products with superior quality are insufficient to keep customers satisfied. They continue that the extrinsic demand varies rapidly, and the products should meet the demand. Changes in products will make workers used to the changes which leads to improvements in processes and emphasized design skills for changes according to (Victor & Boynton 1998, according to Pakkanen 2015, p. 18). This understanding about production processes, interactions and interdependencies leads to architectural knowledge. Architectural knowledge enables understanding about work process structures, their interconnections and the possibilities for reconfiguring them to new combinations or sequences. It is a key for systematic adaptation into processes that leads to producing products that the customer wants. These are the basic characteristics of mass customization. (Pakkanen 2015, p. 18)

By configuring companies are usually trying to achieve several benefits. Configuration work is taking into consideration and managing the needs of customers. Configuration reduces delivery times and costs. Uniformed quality is achieved when utilizing configuration. Configuration is also a way to manage product range and to strengthen a corporate brand. (Lehtonen 2007, p. 72)

Customization work includes activities such as standardizing systems and offering high-quality services on a large scale. Market listening and management of customer context knowledge can be merged into customization work. Customization work reuses information and knowledge from internal processes and external needs. Customization work also underlines the changes in individual demands which are the drivers for reconfiguration of people, information, products, services and processes. (Victor & Boynton 1998, according to Pakkanen 2015, p. 18)

(Hvam et al. 2008, p. 24) divides companies into three different categories; mass production companies, one of a kind producers' companies, and small series production companies. The division of companies is illustrated in Figure 18.

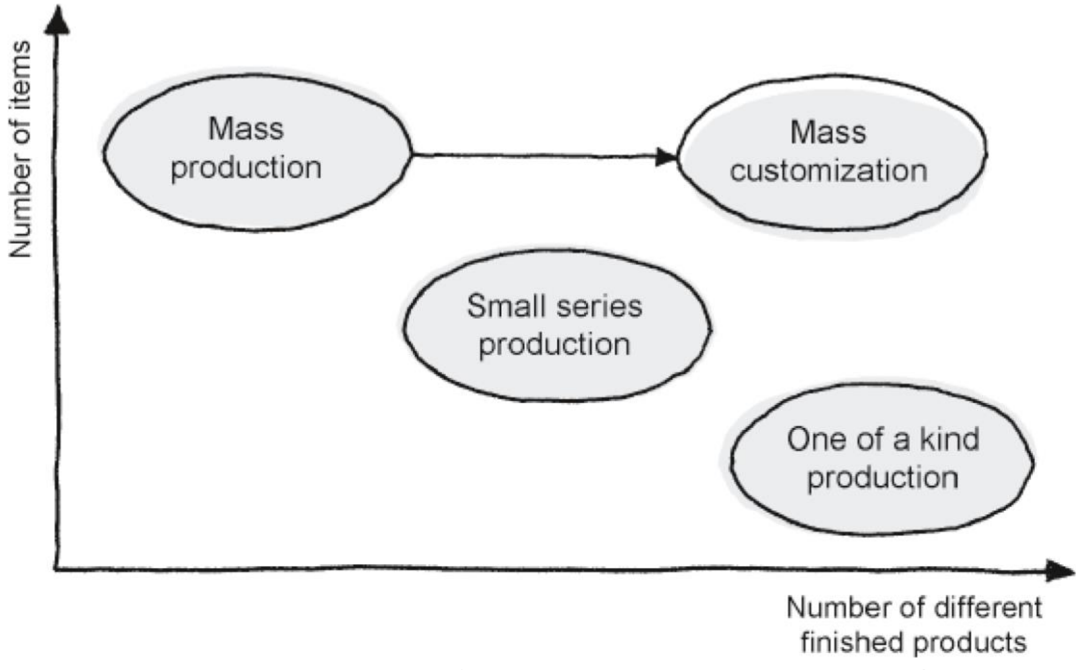


Figure 18. *Three types of industrial companies according to (Hvam et al. 2008, p. 25).*

All types of companies need to focus on the company's specification due to a general tendency for adapting products that they match to the individual customer's current needs according to (Hvam et al. 2008, p. 23). On the other hand, systematic configuration enables creation of products that meet the customer-specific requirements in a profitable way according to (Lehtonen 2007, p. 72). The challenges differ among these different types of companies (Hvam et al. 2008, p. 25). Commonalities for any kind of companies are the processes including chain of activities to achieve specifications which are the basis for being able to sell, manufacture, use and dispose of a product according to (Hvam et al. 2008, p. 25-26). Applying these principles of mass customization for all types of companies means that a module-based product range needs to be built up, and that configuration systems are to be used to support the task of working out specifications in the customer-oriented business processes (Hvam et al. 2008, p. 23-26).

Before a company is ready to start using modules and configuration systems it needs to develop a product range and certain types of business processes that are stable over time (Hvam et al. 2008, p. 26). These developments usually need to be based on a focused market strategy so that the company chooses which customers it wants to service, and which customers not to sell the products to (Hvam et al. 2008, p. 26).

5.2.3 Modules

There are several definitions for modularization, modules and interfaces in the literature. These terms need to define before applications of them can be presented. Definitions of module, modularization and modularity according to (Andreasen 2011, pp. 302 - 303) are described below:

“A module is a product entity, which from a function or organ point of view has distinct function and requested properties, but at the same time such interfaces and interactions with other entities that you can see it as a building block in the parts structure.”

“Modularisation is aiming at creating variety seen from the customer’s viewpoint, whilst at the same time showing kinship or commonality between module variants, and such structural properties, that it reduces the complexity in the company’s operations.”

“Modularity is a relational property; it has no meaning to analyse and describe a product’s seemingly modular structure unless its fit to a certain company area is known: how benefits of modularisation are created”

(Bruun et al. 2014) present four rules to define a module:

- *Active choice.* A module is a module after there is an active choice behind.
- *Documentation.* A module must be documented in a way that novices get the definition too.
- *Responsibility.* There is a team which has the continuous ownership of the module.
- *Continuous development.* A module needs to be actively developed and frequently updated.

(Harlou 2006, p. 81) defines a module as follows:

“A module is one or more design units that are encapsulated into a module and that comply with the module drivers.”

“Module drivers” are defined by Erixon 1998 in Chapter 5.3.3. As can be seen from the module definition earlier by (Andreasen 2011) interfaces are partly defining a module. Interfaces are considered in the following chapter.

5.2.4 Interfaces

A lot of different definitions for interfaces can be found from the literature. (Parslov & Mortensen 2015, p. 183) give a definition for the interface in a following way:

“An interface defines a functional or physical relation between two mating system elements across which interaction may occur.”

Ullman (1992, according to Parslov & Mortensen 2015, p. 186) defines an interface as follows:

“*the boundary area between adjacent regions that constitutes a point where independent systems of diverse groups interact*.”

(Ulrich 1995, p. 421) defines an interface:

“Interacting components are connected by some physical interface. Interfaces may involve geometric connections between two components, as with a gear on a shaft, or may involve non-contact interactions, as with the infrared communication link between a remote control and a television set.”

(Miller & Elgård 1998) state that for modules an interface needs to have functionality between other modules. When there are standardized interfaces existing but no functionality it is a set of building blocks but not modules (Miller & Elgård 1998). For example, lego-blocks have standard interfaces but usually not a considerable amount of functionality between each other’s (Miller & Elgård 1998).

According to the earlier definitions of an interface there can be seen several variations depending on the source. (Parslov & Mortensen 2015, p. 184) state that there is a common impression about the importance of interfaces. One of the reasons that the definitions of the interfaces in the literary still differ a lot is that people adopt different technical disciplines concerning the functionality, and also to the interfaces of the products (Parslov & Mortensen 2015, p. 184). For example, a direct current (DC) motor can be seen from a mechanical or an electrical designing point of view and there can be a lot of differences about understanding functions, structure and interfaces (Parslov & Mortensen 2015, p. 184). According to (Parslov & Mortensen 2015, p. 192) state that in many organizations people tend to underestimate the extent of the interface and are easily using the word according to only their own conceptual viewpoint. They continue that in a complex multi-technological product it might be a significant source of inefficacy if the understanding of the interfaces and product's disintegration into modules vary in the development phase (Parslov & Mortensen 2015, p. 184).

An interface can be fixed, moving or media transmitting. Fixed interfaces just connect the modules into a product and transmit forces. Moving interfaces transmit power, for example by rotation. Media transmitting interfaces can be material, fluids, electricity etc. (Erixon 1998, p. 83)

Another issue concerning the definition is a distinction between an interface (structural) and interaction (functional) (Parslov & Mortensen 2015, p. 185). This can be approached by the consideration if we are talking about a single or about two entities (Parslov & Mortensen 2015, p. 186). By this division it can be recognized if the definition is about structural or functional meaning (Parslov & Mortensen 2015, p. 186). It is crucial to capture both, functional and structural perspectives to disintegrate modules and enable concurrent engineering state Ulrich and Eppinger (2012, according to Parslov & Mortensen 2015, p. 191)

(Parslov & Mortensen 2015, p. 192) found 13 different manifestations of an interface from the literature. According to their research about a half of the perceptions were considered to belong to the elements versus being a separate design object. As a conclusion they state that there is a lack of consensus of the nature of an interface in engineering design (Parslov & Mortensen 2015, p. 196).

Harlou has another approach concerning interfaces. He states that the ownership of the interfaces can get complicated when there are different types of interfaces recognized as interfaces to surroundings, and interfaces between modules. He continues that there are three different kinds of methods to define ownership of the interface: the owner of the architecture owns the interface; the owner of the module owns the interface, or each interface is appointed an owner. The interfaces owned by the architecture aims managing the development of product families and modules. The second option is to let the owner of the module have the responsibility of the interfaces. The main idea here is that the people who are working daily with the interfaces have the responsibility of the interfaces. In this approach challenges can arise from the scattered management of the interfaces among modules. The third option is to appoint one owner to each interface. In this case the ownership of the interfaces is independent of the module and architecture owners. The appointed owner of the interface has the responsibility of specifying, developing, documenting and maintaining the interfaces by cooperation with the architecture and modules. (Harlou 2006, p. 88)

5.2.5 Architecture

According to (Harlou 2006, p. 21) architecture is a building principle for individual products in a product family. An architecture enables re-use of building principles and standard modules (Harlou 2006, p. 21). (Pakkanen et al. 2013, p. 94) divides architecture into closed and open architecture. This division is described in Chapter 5.4. Preliminary architecture description includes modules and interfaces of the modules according to (Pakkanen 2015, p. 68). It will give cumulative advantages if the product architecture has platforms, modules and components with interfaces so that they can be assembled in different ways to offer customer-specific products (Stark 2015, p. 350) states.

Architecture is a link between physical structure and functionalities of the product (Stark 2016, p. 141). Product architecture defines the functions that will be performed in which assembly (Stark 2016, p. 141). Architecture determines how the product is assembled and it has the impacts through the whole lifecycle of the product, for example it affects production, support, service, suppliers and customers (Stark 2016, p. 141). All the parties have their own opinions of the kind of architecture that is suitable for their needs (Stark 2016, p. 141). Production would like to have a product which is easy to manufacture and assemble, service would ask for a product which is easy to disassemble (Stark 2016, p. 141). Customers provide demand for products that are inexpensive (Stark 2016, p. 141). For these reasons, companies need to give a lot of effort to achieve a good product architecture. (Stark 2016, p. 141)

To achieve the needed flexibility and commonality among the architecture Kreimeyer et al. (2014, p. 6) suggest using Architectural Standards for a modular product. The aim is to increase intrinsic commonality and ease handling of space reservations. In Figure 19 architectural standards are divided into three main categories; functional, technological and geometrical variance.

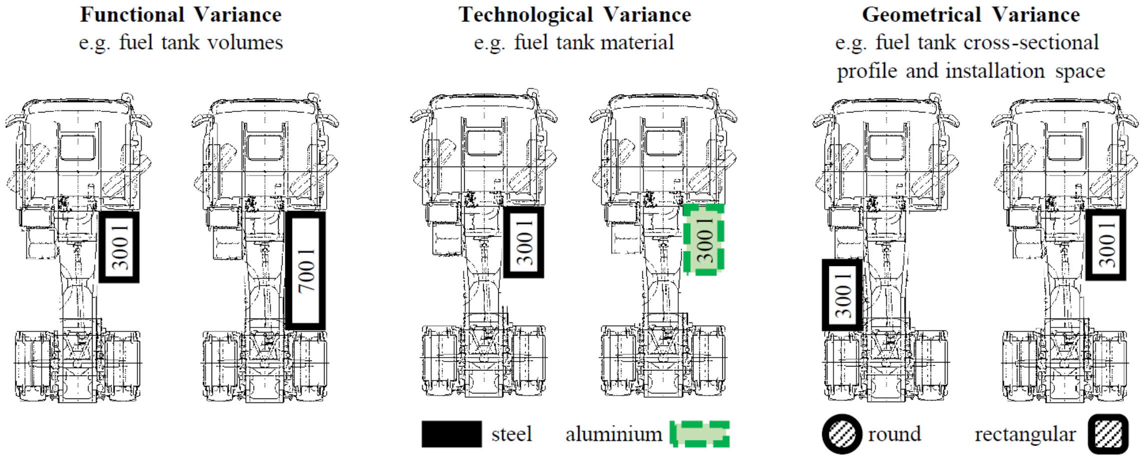


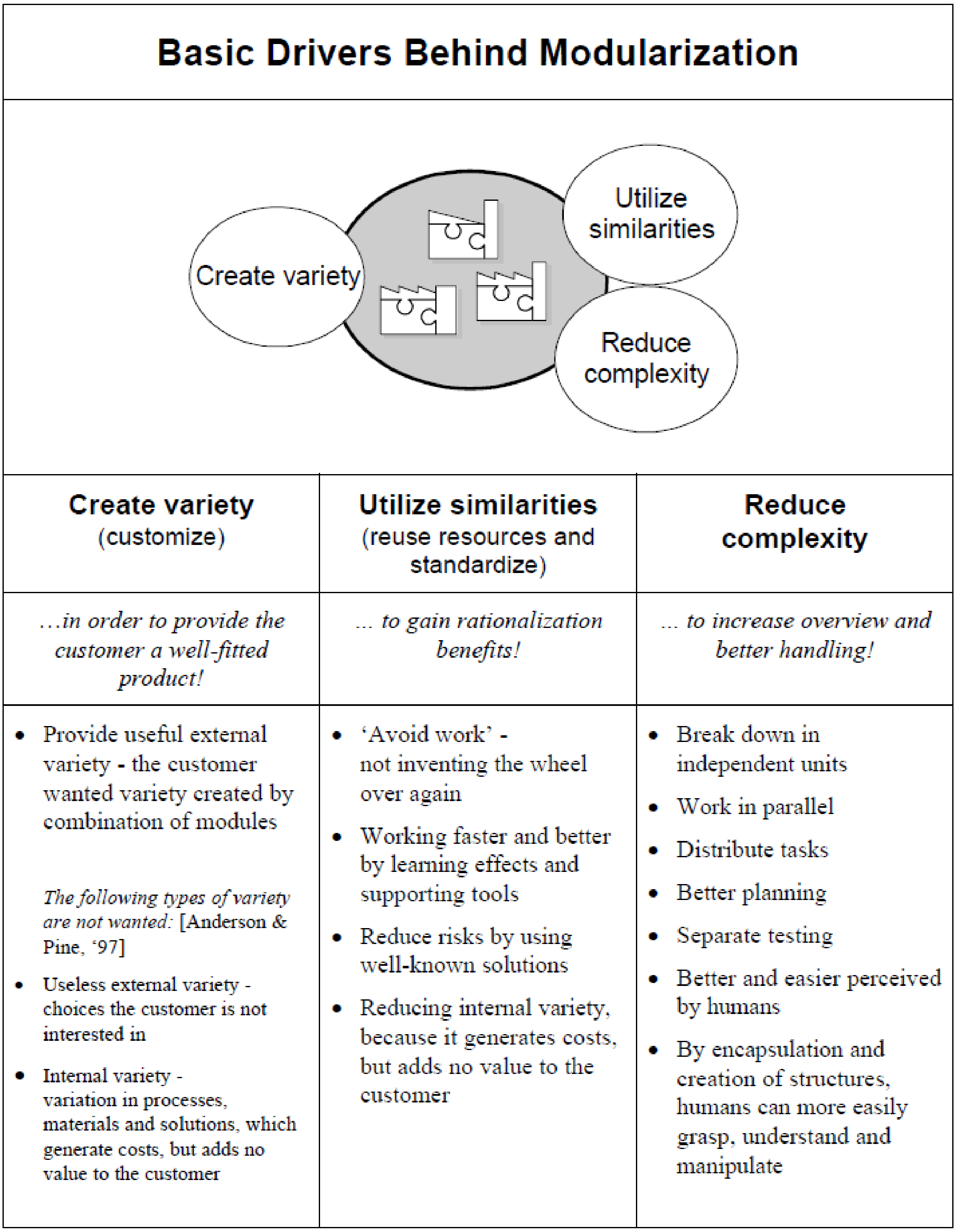
Figure 19. *Architectural Standard types according to Kreimeyer et al. (2014, p. 7)*

The purpose of functional standard is to reduce different functional variants. In this case there is supposed to be limited number of different sizes of fuel tanks. An example of technological standard is the material of the fuel tank. The geometrical standard divides into part-related and position-related types. An example of part-related standard is the cross-section profile of the fuel tank. Position-related standard is a standard installation space for the fuel tank in this case. By this division it is easier to perceive the variants with low demand. Kreimeyer et al. (2014, pp. 6-7)

5.2.6 Modularization and modularity

There must be always a specific need or goal for modularization. When there is clear objective for modularization it is possible to apply sub goals and measure the benefits of modularization. In this chapter some of the possible reasons to implement a modular product are presented.

The basis of modularization stands behind standardization. Standard components and interfaces enable the use of modules. According to (Pahl & Wallace 2007, p. 374) designers should in most of the cases try to prefer standard components, repeated components or bought-out parts instead of specially produced ones. (Pahl & Wallace 2007, pp. 374-375) continue that following these principles a company can create favorable supply and storage conditions and bough-out parts are also usually easily available and cheaper compared to made in-house parts. Figure 20 shows “utilize similarities” and “reduce complexity” that represent the idea of standardization and “create variety” in representing customization as described in the section 5.2.2.



Basic Drivers Behind Modularization

Create variety (customize)	**Utilize similarities** (reuse resources and standardize)	**Reduce complexity**
...in order to provide the customer a well-fitted product!	*... to gain rationalization benefits!*	*... to increase overview and better handling!*
• Provide useful external variety - the customer wanted variety created by combination of modules *The following types of variety are not wanted:* [Anderson & Pine, '97] • Useless external variety - choices the customer is not interested in • Internal variety - variation in processes, materials and solutions, which generate costs, but adds no value to the customer	• 'Avoid work' - not inventing the wheel over again • Working faster and better by learning effects and supporting tools • Reduce risks by using well-known solutions • Reducing internal variety, because it generates costs, but adds no value to the customer	• Break down in independent units • Work in parallel • Distribute tasks • Better planning • Separate testing • Better and easier perceived by humans • By encapsulation and creation of structures, humans can more easily grasp, understand and manipulate

Figure 20. *Modularity drivers according to (Miller & Elgård 1998).*

According to (Lampel & Mintzberg 1996, p. 21) standardization and customization are two opposite balancing forces even though for many years it was common to think that a company needed to choose only one of them.

(Hvam et al. 2008, p. 30) state that the use of modules is closely connected with the use of product configuration. Modules are building blocks of the Module System which is described in Chapter 5.4. by (Pakkanen et al. 2013). The object of development and usage of modules is partly to achieve customized products for the market and partly to reduce the number of variants which must be dealt within the company, and hence reduce complexity and costs continue (Hvam et al. 2008, p. 30).

(Lehtonen 2007, p. 89) is using term “life-cycle-based modularity” for the type of modularity (see the definition in Chapter 5.2.3) which not aims to customize the product (utilize similarities and reduce complexity according to Miller & Elgård 1998). (Lehtonen 2007, p. 89) divides life-cycle-based modularity into three different types of modularity:

- Modularity based on reasons of manufacturing
- Modularity based on reasons of maintenance
- Modularity based on logistical reasons

This division is illustrated in Figure 21:

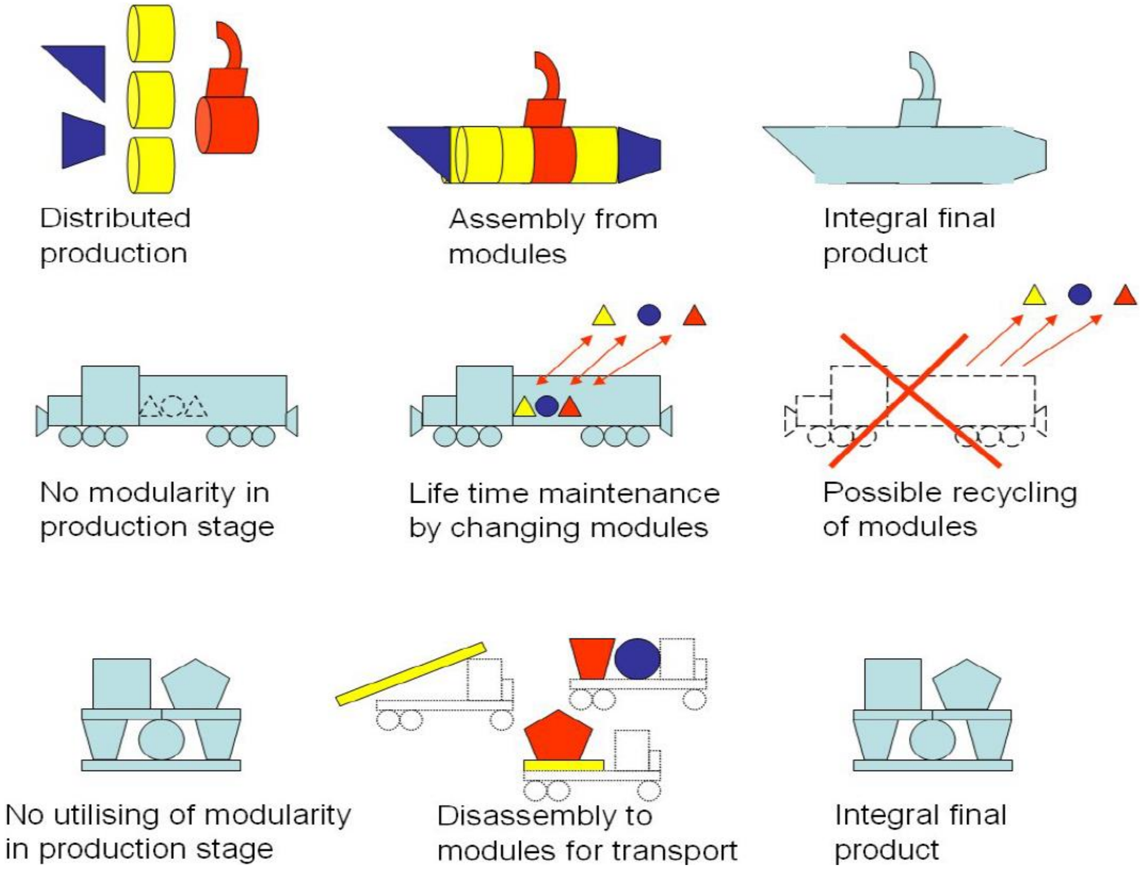


Figure 21. *Life-cycle-based modularity, colored parts are representing lifecycle phases where modularity is applied (Lehtonen 2007, p. 90).*

In the modularity based on manufacturing (first row in Figure 21) a submarine is divided into assembly modules to enable decentralized production and the modularity is not utilized after the manufacturing phase. (Lehtonen 2007, p. 89). Maintenance based modularity is applied in the second row where crucial electrical steering system components are grouped into the replaceable rack to increase usability (Lehtonen 2007, p. 90). In the modularity based on logistical reasons in the last row the entity is disassembled to be transported in modules but otherwise modularity is not utilized (Lehtonen 2007, p. 90). As far as a product is purely life-cycle modular there is no variation in the product structure so there is no need for modularity in the sense of customization (Lehtonen 2007, p. 90).

5.3 Modular Function Deployment

There are many kinds of research and development methods to create modular products. Modular Function Deployment (MFD) is described in this chapter. MFD do not consider the detailed product data management or designing aspects. Still MFD has a significant impact on design methodologies when applying it efficiently.

MFD is a supportive method for companies for finding the optimal modular product structure. The optimal product structure can stand for manufacturability, serviceability, recyclability etc. and for some combination of them depending of the case. MFD takes into consideration the specific needs of the company. MFD offers the entire concept from a product idea to a scrap yard. The method can be implemented for entire product assortment of the company and it works most efficiently by a cross functional work group. There are five major steps in MFD:

1. Define customer requirements
2. Select technical solutions
3. Generate concepts
4. Evaluate concepts
5. Improve each module

All the steps are described separately, and they are illustrated in Figure 22.

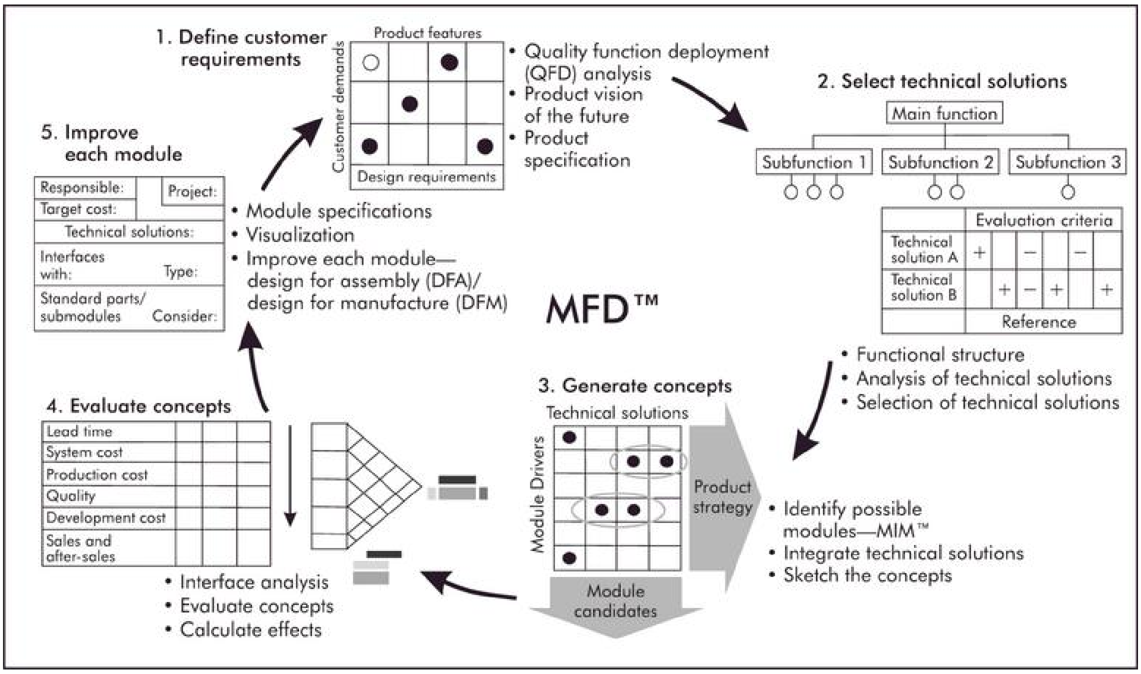


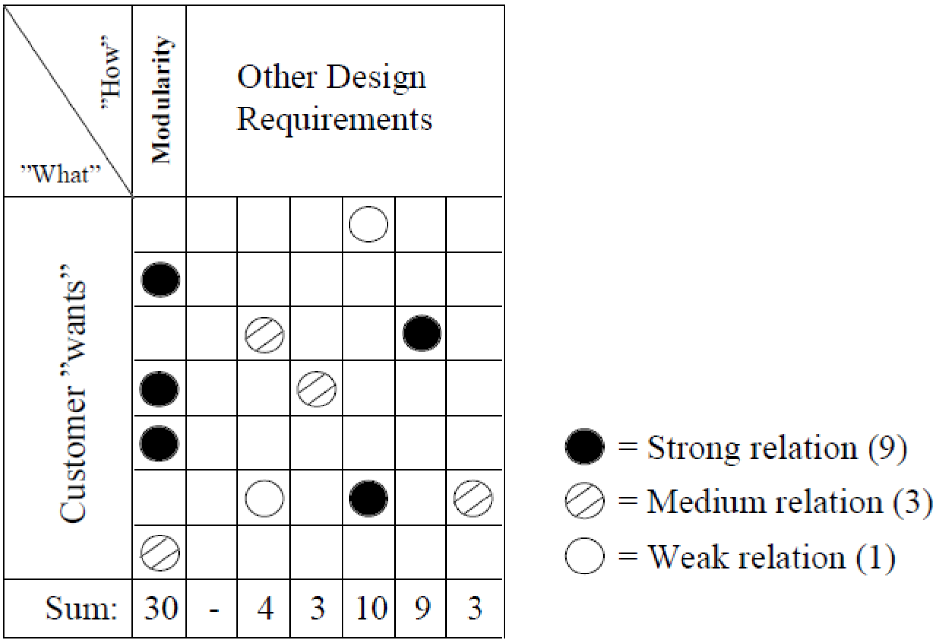
Figure 22. *Five steps of Modular Function Deployment according to Ericsson & Erixon (1999, p. 30)*

The presented MFD steps describe the ideal module system creation process. The practical process is not always starting from the first step and ending to the fifth step. The process should be a guiding principle for practical work and a lot of iteration might needed depending from the starting point of the company. Ericsson & Erixon (1999, pp. 29-31)

5.3.1 Step 1: Define customer requirements

The first step ensures that the design requirements are gathered from the customer demands. The aim is to satisfy current and future customer demands. This information is collected by and defined by an analysis of competition and customer requirements. Ericsson & Erixon (1999, p. 29)

For the first step Erixon recommends using Quality Function Deployment (QFD) analysis. In Figure 23 QFD is illustrated. QFD is used to define customer requirements and to consider them with the design requirements by a scale 0,1,3 or 9. He suggests choosing modularity as the first design requirement in QFD to make sure that the mindset is suitable for the research and development task. By doing this the first check has made to ensure that modularization supports to fulfill the customer demands.



"How" / "What"	Modularity	Other Design Requirements					
Customer "wants"					○		
	●						
			▨			●	
	●			▨			
	●						
			○		●		▨
	▨						
Sum:	30	-	4	3	10	9	3

● = Strong relation (9)
▨ = Medium relation (3)
○ = Weak relation (1)

Figure 23. Quality Function Deployment according to Erixon (1998, p. 67)

Erixon states that by placing modularity to the first place in QFD creativity is encouraged and new ways of thinking are perceived in case studies. Also, in case studies QFD has turned out to be suitable to make sure that the right input data from customer is gained. (Erixon 1998, pp. 65-66)

To achieve best results Erixon gives some recommendations how to use QFD. There needs to be clearly defined goals for project to be able to measure the results of work. The starting point for the competitive position needs to define before starting the project. The scope of the project needs to be defined in an early phase in consideration of market segment, laws and regulations, project budget, project schedule etc. The extent and amounts of customer questionnaires should be focused and minimized. Time to market is more crucial and this phase should not take too much time. The amount of customer requirements needs to be limited only into the most important topics otherwise the amount of data grows, and it is not easy to manage. The design requirements need to be considered systematically, only the prime design objects should be chosen. It is good to keep in mind that the QFD is used as a preliminary tool in this phase and there should not be one and only solution for the product. The aim is to achieve flexible product design that is easy to update according the requirements changes. (Erixon 1998, pp. 67-69)

5.3.2 Step 2: Select technical solutions

In the second step the technical solutions that corresponds the needed functions identified in the first step are under consideration. There can be variation of technical solutions to execute a specific function. Only the most suitable solution needs to be chosen according to the customer requirements and the strategy of the company. Ericsson & Erixon (1999, pp. 30-31)

In the second step the product is considered from a functional view instead of customer standpoint. The product is divided into sub-functions and this partition is compared with the corresponding technical solutions. This method is defined as a functional decomposition and it supports the modular product designing task. Going through the functions and technical solutions is crucial to achieve a common understanding in the design team and how the parts and assemblies are connected to the whole solution. In addition to the product decomposition and the agreement of solutions well-structured specifications are needed. (Erixon 1998, p. 69)

An efficient modular product design ensures the independence of functions and technical solutions. The idea is to minimize interactions between the modules. The result is called “a stand alone module” and it can be treated individually without dependencies to the other modules. (Erixon 1998, p. 69)

For the second step Erixon gives recommendations to implement decomposition. It is necessary to keep in mind that functional decomposition is not the main purpose and it is no more than a tool to achieve efficient communication and cooperation among the teams. Structured methods such as a design matrix, combine functions and technical solutions as a tool that provides a good overview of the interdependencies of functions and solutions. The matrix also shows the challenging areas of the design. For complex products the functions and technical solutions are mandatory to describe by hierarchical structure to ensure insight of the whole. This can be done in different ways, but one suggested method that has been useful in case studies is called “functions and means tree”. An illustration of the functions and means tree is in Figure 24.

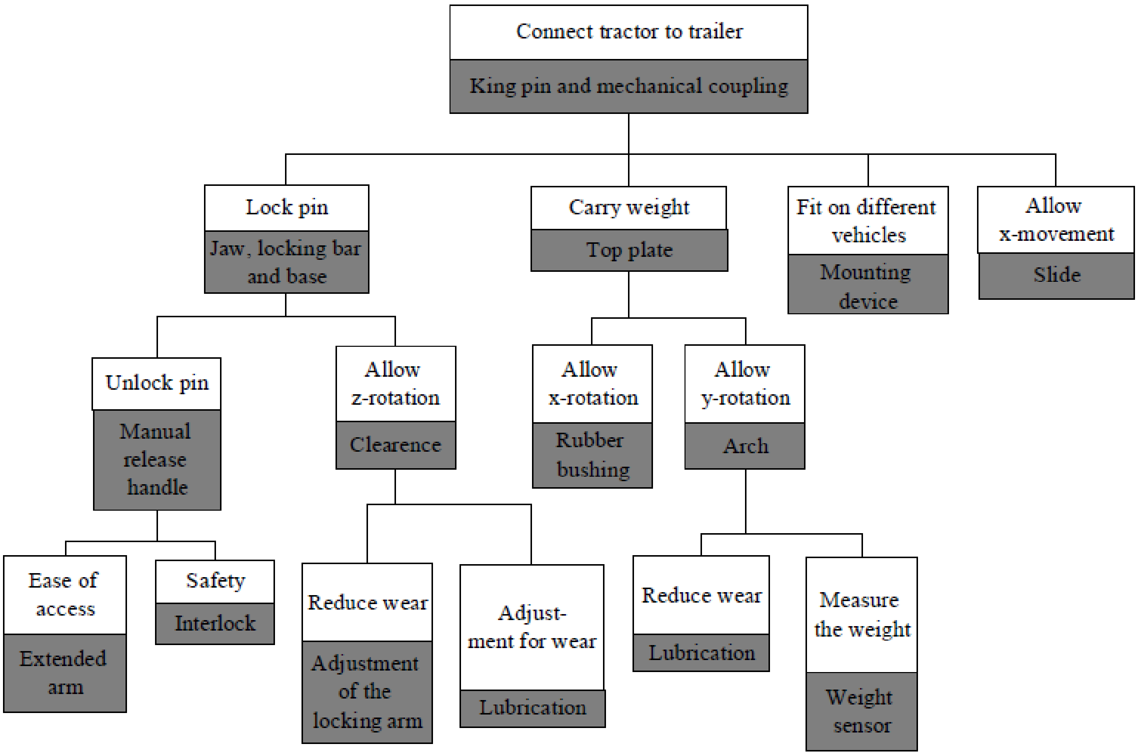


Figure 24. *Functions and means tree for a wheel (Svendsen & Thorp Hansen 1993, according to Erixon 1998, p. 70)*

It is useful to find out the nature of sub-functions. The functions that are needed by every customer are the necessities and need more priority. Further the sub-functions that are not requested by all customers are optional and the last importance is for customer specific sub-functions. The decomposition should not go too deeply into the details. Not every screw and nut need to be considered. It is better to stop going into the details earlier rather than later. It is beneficial to identify all the technical solution variants for the specific function and consider if their existence is mandatory. Just like in the first step it is good to keep in mind that there is not only one and only solution for the functional analyses. The purpose of the second step is to achieve a common and agreed overview of the problems. Integrating technical solutions should not be considered at this point because the integration will be tested in the following steps. (Erixon 1998, pp. 69-71)

As a result of this step there can be variation of technical solutions for different functions. As mentioned before the objective is to have only one solution for a specific function and the selections need to be made. The options need to be considered systematically to achieve the best solution. The suggested method is to pick one of the alternatives or an existing solution as a reference. All the other possible variants are compared with the reference and iteratively the weakest solution is discarded until there are only two solution candidates. This ensures that behind the selection there are no personal interests or irrational reasons. (Erixon 1998, pp. 71-72)

5.3.3 Step 3: Generate concepts

In the third step the results from previous steps are used as a basis to consider possible technical solutions for being modules. Here the module drivers are in the focus and technical solutions are options to realize the module drivers. Ericsson & Erixon (1999, p. 31)

Erixon presents module drivers based on findings in case studies. Module drivers can be found in the entire product lifecycle. Module drivers are:

Product development and design

- Carry over
- Technology evolution
- Planned product changes

Variance

- Technical specification
- Style

Production

- Common unit
- Process and/or organization re-use

Quality

- Separate testing

Purchasing

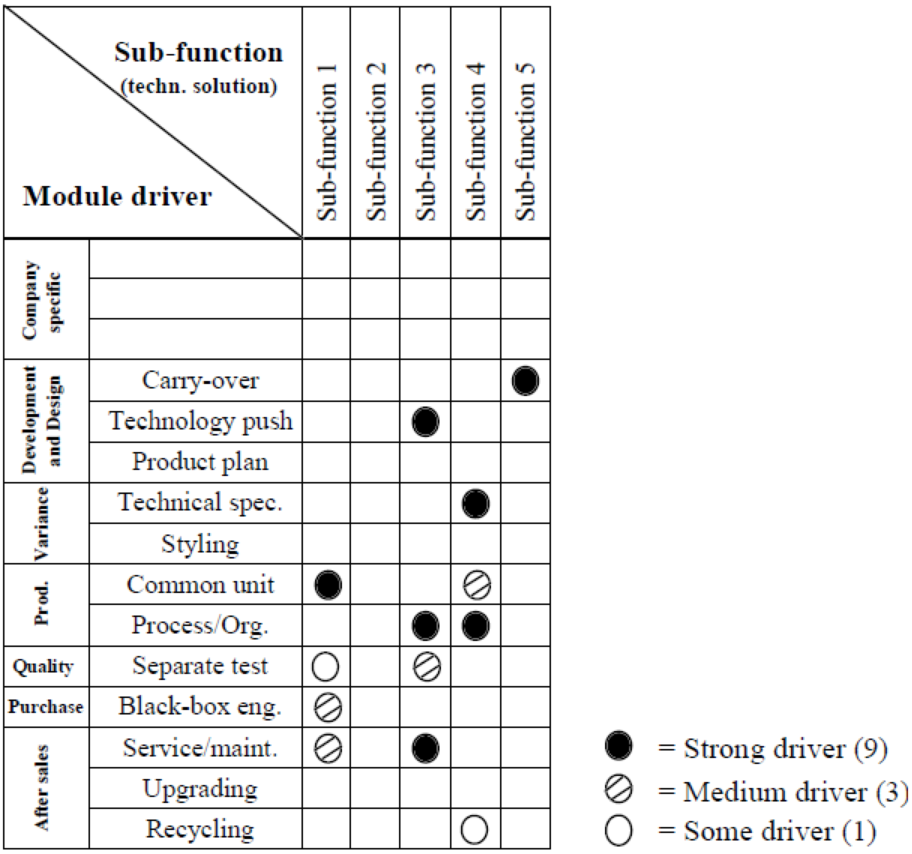
- Supplier offers black box

After sales

- Service and maintenance
- Upgrading
- Recycling

The module drivers above are generic. There can be additional company-specific module drivers related to strategy, financial limitation, legal restrictions etc. The generic module drivers above are suggested and considered in a matrix with every sub-function identified in the second step. It is crucial that the sub-functions are translated into technical solutions in detail to be able to have reasonable comparison between solutions. (Erixon 1998, pp. 72-77)

The matrix where sub-functions are compared against generic module drivers is called Modular Indication Matrix (MIM) and is illustrated in Figure 25.



Module driver		Sub-function 1	Sub-function 2	Sub-function 3	Sub-function 4	Sub-function 5
Company specific						
Development and Design	Carry-over					●
	Technology push			●		
	Product plan					
Variance	Technical spec.				●	
	Styling					
Prod.	Common unit	●			⊘	
	Process/Org.			●	●	
Quality	Separate test	○		⊘		
Purchase	Black-box eng.	⊘				
After sales	Service/maint.	⊘		●		
	Upgrading					
	Recycling				○	

Figure 25. *The Module Indication Matrix with generic module drivers according to Erixon (1998, p. 78)*

The MIM is the most important part in MFD and the module division is implemented here respecting the simplification that every sub-function is isolated into a module. The approach in MFD is similar with QFD in the first step. As can be seen in Figure 25 in the MIM each sub-function is weighted in a scale 0, 1, 3 or 9 by importance compared to the module drivers. The scale emphasizes the strong module drivers. (Erixon 1998, p. 77)

Sub-function testing one at a time against the module drivers will show which technical solutions have the most reasons to form a module. In every individual case the importance of generic module drivers varies. Therefore, all the module drivers need to go through to consider which module drivers are more important compared to the others. The corresponding sub-functions for module drivers that have more importance are proposed to form a module. On the other hand, the sub-functions that are connected to the less important module drivers can be integrated to other sub-functions. There are also module drivers that are not so easy to combine. For example, carry-over and technology push leaded sub-functions are not easy to integrate into a same module. MIM reveals which sub-functions have the same or contradictory module drivers. In this step it is intended to start forming suitable groups of subfunctions according the results from MIM and changes to the module choices should be avoided after the step. Cooperation among the designer team is important in this phase to achieve an agreement about the module division. It is suggested to form couple of different solution proposals with rough dimensions. Then, one or more of them are chosen for more detailed consideration. If multiple module divisions are chosen, they can be compared in a similar way as the technical solutions in the second step. One division proposal is picked as a reference and the others are compared to this and one by one the weakest solution is discarded iteratively. (Erixon 1998, pp. 78-83)

5.3.4 Step 4: Evaluate Concepts

In the fourth step the module concepts are finalized. Interfaces for modules are derived and evaluated. Upcoming effects due to modularization are considered and economic forecasts are calculated. Ericsson & Erixon (1999, p. 31)

This step is important to evaluate the efficiency of the modularization. The results here are also feedback for the earlier MFD steps. One of the most important factors to measure about the modular design are the interfaces. Interfaces represent the key factors on flexibility among the product assortment. Interface connections also have an important role on the product's performance. (Erixon 1998, p. 83)

For evaluation interfaces from the assembly perspective a matrix tool is represented in Figure 26. To assemble the modules there are two main approaches; "base part" and "hamburger" assemblies and the order for assembling is according to the arrows. These ideal approaches support simultaneous development, simple process plans and agile workshop organization etc. The disadvantage of these ideal approaches is the assembling itself. As can be seen in Figure 26 the arrows represent these two approaches. All the connection types for modules that are not following the ideal approaches (outside of the arrowed area) should be avoided and if cannot the connectivity needs extra consideration.

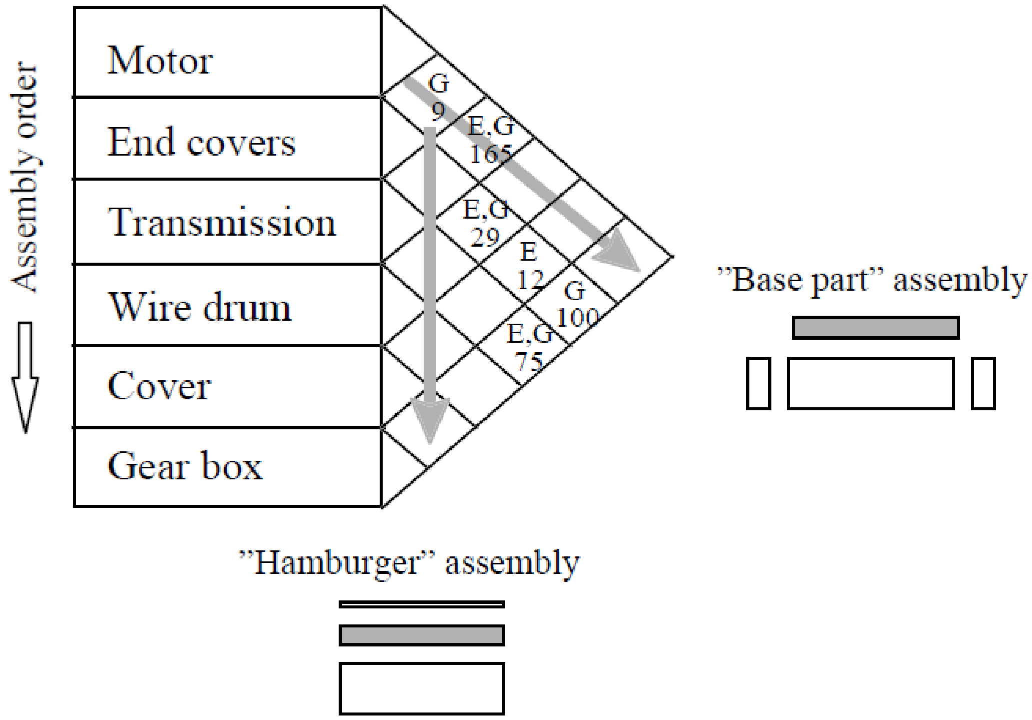


Figure 26. *Interface evaluation tool according to Erixon (1998, p. 84)*

Moreover, in Figure 26 "E" represents energy transmitting and media transmitting forces, inertia, electricity etc. and correspondingly "G" is for purely geometrical connection. The numbers stand for counting the assembly operations. The tool in Figure 26 is useful for recognizing the important interfaces between the modules. (Erixon 1998, p. 84)

The module concept needs to be evaluated also from economic aspects. The central questions are connected to measurement of the value of well-designed modular product assortment and how to measure cost savings during the product's lifecycle. Also, the saved time in product development phase is a significant factor. (Erixon 1998, p. 85)

5.3.5 Step 5: Improve each module

In the fifth step specifications for modules are created. The specification includes at least technical information, target costs, development plans and information about module variants. All the modules can be improved separately for example, by common methods such as Design for Manufacture and Assembly (DFMA) that improves the module from manufacturing and assembling point of views. Ericsson & Erixon (1999, p. 31)

The MFD process is not contrary for the design work and MFD is not going to replace it. A need for design improvements on a detail level is crucial for every module to achieve an efficiently functioning product. The design work needs to be done on every product level: product assortment level, product level and part level. The MIM that was introduced in the third step is a useful tool in this step again but now it is used for modules instead of sub-functions. For every module the module drivers need to be clear for everyone working with the module to achieve a module that serves the dedicated purposes. For example, for a module that has service as a module driver then technical decisions need to support the disassembling of the required components. (Erixon 1998, p. 103)

One of the measurable goals for determining costs for a product is the number of parts. The cost of a part for a company varies depending of the size and type of the company. A new part causes a lot more expenses for the company compared to the existing ones. The increase of part number count causes cost not only for a single module variant but instead for the whole product assortment. For these reasons it is necessary to be careful when exploiting Design for Assembly (DFA) methods for an individual module variant but not for the whole product assortment. (Erixon 1998, p. 105)

5.4 Brownfield process

The Brownfield process (BfP) considers the main viewpoints of modularity. It is intended to support development of a modular product family in a context of manufacturing industry. The first version of Brownfield process was introduced by Lehtonen et al. (2011). The first version includes five phases:

1. Defining (business) targets
2. Drafting the proposed module architecture using mainly old solutions and components
3. Updating and rationalizing the market and customer requirements

4. Creating module architecture with minimum scale of variation. Defining the amount of new
5. Documenting the reasoning behind the selected module architecture

In addition to these phases the sixth phase was under consideration. The sixth phase was intended to evaluate cost and income effects of the selected solution and compare them with the business targets defined in the first phase. In this first phase the purpose of the project is indicated. After the objective and reasons for the project are verified starts the product division into draft of generic elements in phase two. Generic elements are discussed more in Chapter 5.4.2. The product variants need to match with the customer requirements, and they are considered in the third phase. According to the results in phase three the minimum variation scale in product range is analyzed in step four. The fifth phase describes the created product structure. Lehtonen et al. (2011)

Pakkanen (2015) updated the BfP by modifying and clarifying the steps. The basic idea of BfP stayed the same. He included new steps to the BfP to make the steps more manageable. The level of details is also increased in BfP. Here the BfP is intended to use for existing products and reusing the available assets. Pakkanen (2015, p. 171)

In the updated BfP there are ten steps and every step are intended to serve design related information for the specific elements of Module System (Pakkanen 2015, p. 171). The updated BfP is illustrated in Figure 27. Pakkanen divides the Module System into five main elements; partitioning logic, set of modules, interfaces, architecture and configure knowledge (Pakkanen 2015, p. 171).

Partitioning logic justifies the reasons for the chosen product structure and module division (Pakkanen et al. 2013, p. 93). Reasoning for applied element types (standard, fully configurable, partly configurable or unique) is included into partitioning logic (Pakkanen 2015, p. 68). Partitioning logic describes aims related to the lifecycle phases of the product and the need of applied variation (Pakkanen 2015, p. 68).

Set of modules are first preliminary modules or generic elements. In the later BfP phases set of modules means detailed modules. Different kind of module suggestions need to be considered due to the technological developments and other points of view. Pakkanen (2015, p. 67)

Interfaces precisely define the module, its interdependency and partitioning of the modules (Pakkanen et al. 2013, p. 92). Definitions and agreements between two or more modules are contained into interfaces (Pakkanen 2015, p. 68). BfP do not follow any specific definition for interfaces (Pakkanen 2015, p. 207). There are definitions for interfaces in Chapter 5.2.4.

Architecture description includes modules and interfaces of the modules (Pakkanen 2015, p. 68). Architecture divides into closed and open architectures (Pakkanen et al. 2013, p. 94). All the modules and their combinations are preliminary defined in the closed architecture (Pakkanen et al. 2013, p. 94). In the open architecture all the interfaces are defined but there are no definitions for all possible modules nor rules for combining them (Pakkanen et al. 2013, p. 94).

Configuration knowledge includes the combability information, constraints of the modules and customer needs (Pakkanen et al. 2013, p. 93). Customer requirements cause variety in product structure and are included in configuration knowledge (Pakkanen 2015, p. 68). Configuration knowledge also includes the information about modules and their technical compatibilities related to customer needs (Pakkanen 2015, p. 68). Configuration knowledge is information which enables the forming of a product variant without engineering design (Juuti 2008, p. 38).

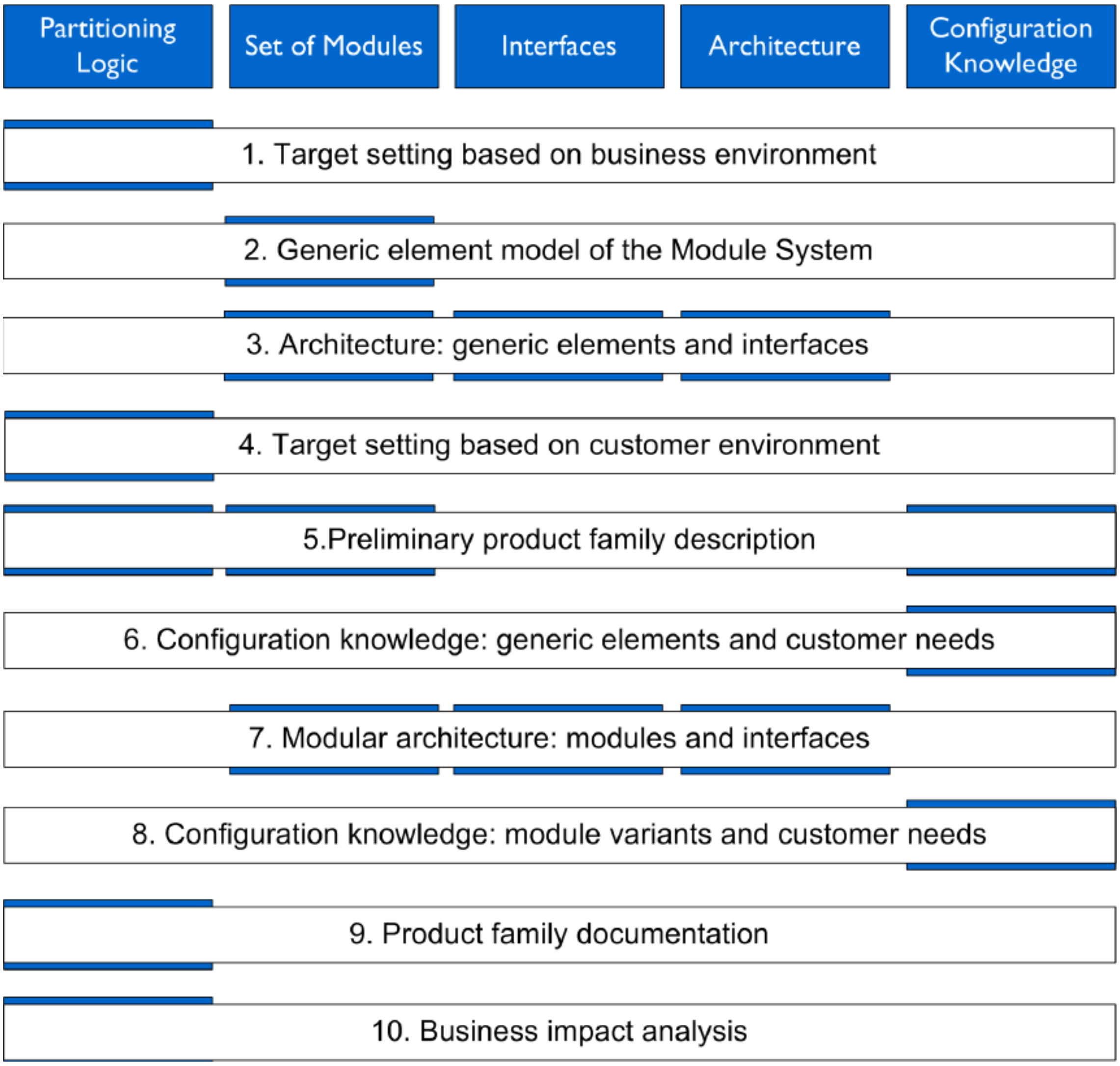


Figure 27. The Brownfield Process with Module System elements according to Pakkanen (2015, p. 172)

In Figure 27 in BfP step relations to the Module System are illustrated. The process starts and ends with business impact consideration. The process steps are considered more in detail in Chapters 5.4.1-5.4.10.

5.4.1 Step 1: Target setting based on business environment

In the first step the aim is to define objectives for modular product family design. As mentioned in Chapter 5.4 the new modular product family has the base in the existing product assortment. The product assortment is intended to get adapted into a modular product family by rationalization and finding commonalities in a way that enable needed variability. (Pakkanen 2015, pp. 183-184)

First the scope needs to be selected based on the existing product assortment. In a case that the product assortment is wide and includes many kinds of product types, it might be useful to limit the scope of products for the BfP. It will simplify the BfP and reduces complexity of the engineering work. The disadvantage of scope limitation is that the benefits of BfP will be restricted among the chosen scope. When the scope is chosen the targets for the process need to be defined. Pakkanen suggests the cause-effect chain by Juuti (2008, p. 6) to clarify the targets. The approach is intended to be exploited in the situations when the project objectives are obvious. It means that there is a common understanding about the advantages of implemented modular structures. Another suggested tool to identify the objectives is the Company Strategic Landscape (CSL) template by Lehtonen (2007, p. 97). CSL template is suggested to use in the cases when the objectives of the BfP are unclear. In CSL the starting point is comprehensively on business environment that is modeled from perspectives of process, value chain, strategy and organization. (Pakkanen 2015, pp. 184-185)

The output of this step requires all the other steps in BfP. The result should serve the organization or a group that will do the actual development work. The objectives and reasons of the project need to be clear for them to achieve the best results. In this phase, representatives of all functions of the company need to be consulted in order to achieve a suitable scope and vision. This phase considers partitioning logic in the context of the Module System. (Pakkanen 2015, pp. 186-188)

5.4.2 Step 2: Generic element model of the Module System

In the second step the preliminary module division is created. This consists of generic elements. A generic element is an abstract construct to create a product structure. Generic elements can be sub-systems, sub-functions, assemblies or single parts. In other words, generic elements are the entities that the case company perceives are their product is constructed of. As the the BfP proceeds generic elements are defined more specifically. In the result of BfP there can be for example, a generic element that includes multiple alternative modules. (Pakkanen 2015, pp. 188-189)

A generic element needs to be technically realizable as a unit and it includes all the requirements to fulfill one variation need. The idea is that the generic elements divides the product into sections that answer to the variation effects of customers. A workshop with experts from different departments for defining generic element division is suggested. In definition work similarities among the generic elements should be avoided. Commonality in generic elements source a risk of unnecessary variation. (Pakkanen et al. 2016, pp. 221-223)

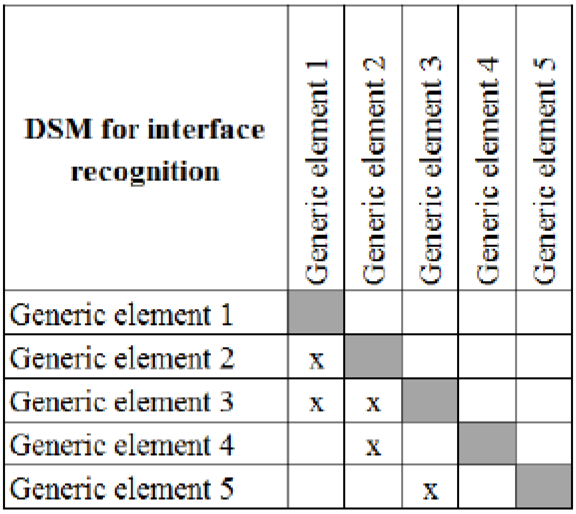
This step is the beginning of module structure design. The aim is to define a list of elements to achieve a preliminary module division. Here the knowledge about existing product assortment is crucial. The step considers “Set of Modules” in the context of Module System. (Pakkanen 2015, p. 191)

5.4.3 Step 3: Architecture: generic elements and interfaces

In this step the architecture is structured by the generic elements defined in the previous step. The generic elements are located physically in the product. The physical positioning of generic elements is important for the consideration of preliminary interfaces. (Pakkanen 2015, p. 191)

In Chapter 5.4 the architecture was divided into open and closed types. Here the existing product was used as a basis for the generic elements the architecture is closed. The interfaces that are defined in this step enables the expansion of the architecture into an open architecture with consideration of future needs. This is also an important factor to define the interfaces clearly. (Pakkanen 2015, pp. 191-192)

A preliminary architecture with generic element division and interfaces can be created in many ways. At first the relations between generic elements need to clarify. For this Design Structure Matrix (DSM) (Steward 1981, according to Pakkanen 2015) is suggested. An example DSM is illustrated in Figure 28.



DSM for interface recognition	Generic element 1	Generic element 2	Generic element 3	Generic element 4	Generic element 5
Generic element 1	▨				
Generic element 2	x	▨			
Generic element 3	x	x	▨		
Generic element 4		x		▨	
Generic element 5			x		▨

Figure 28. *Design Structure Matrix according to Pakkanen (2015, p. 192)*

The matrix is used to illustrate the needed interfaces between generic elements. (Pakkanen 2015, p. 192)

When the interfaces between generic elements are recognized the next objective is to illustrate generic element positioning for the product. An example of architecture in BfP is in Figure 29.

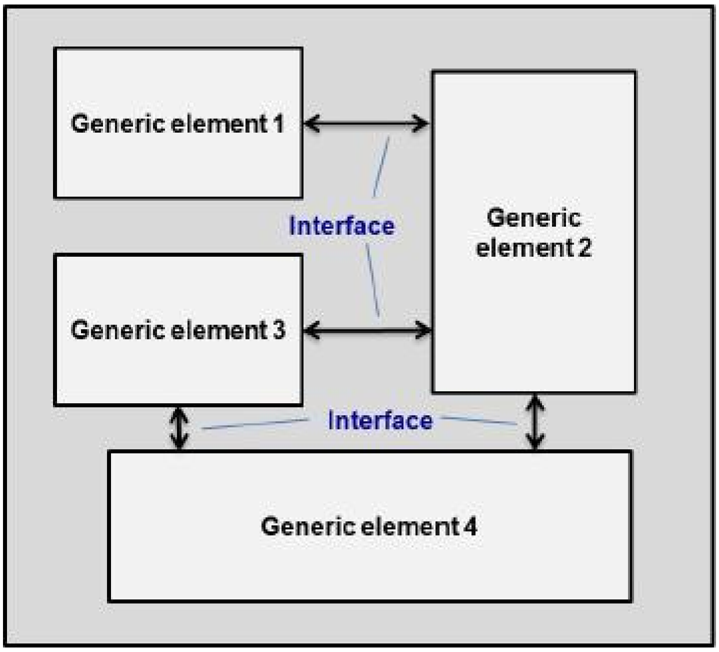


Figure 29. An architecture visualization in an early phase of the BfP according to Pakkanen (2015, p. 193)

In this phase there is no need for detailed interface consideration as the division and interfaces will become more accurate in the later phases. (Pakkanen 2015, p. 193)

This needs the generic elements as an input and the step is a starting point for interface consideration (Pakkanen 2015, p. 193). For this step architecture, set of modules and interfaces are under consideration in the context of Module System (Pakkanen 2015, p. 193). Visual product models described in Chapter 5.1.12 can be exploited to support this step.

5.4.4 Step 4: Target setting based on customer environment

As the BfP is for existing products there are also customers for the products. When the product assortment is changed from delivery-specific solutions to predefined products the importance of adaptation into the customer environment is emphasized. The customer requirements need to be defined precisely and in details to support configuration rules. If the customer requirements are not defined carefully the benefits of BfP are reduced. (Pakkanen 2015, p. 194)

The customer requirements need to be up-to-date and valid. The needs of customers probably have changed, and the existing products must be excluded from the consideration. In the BfP the Gripen approach is suggested to determine the customer requirements. The Gripen approach has its base on understanding the processes of customers when they use the product. It suggests combine the similar technical variety needs into the same category. Instead of individual components the Gripen approach suggests offering larger solutions and assemblies. By them the company can limit the amount of variable solutions that ease the design work. By a comprehensive solution the compatibility issues are reduced, and better functioning is achieved. (Pakkanen 2015, p. 195)

In this step the focus is on customer variation needs. It is assumed that there are existing products and customers. This knowledge is required in this step so at least the sales should participate in this phase. The result of this step is the customer context and ways to manage it. This step belongs to the partitioning logic by the division of Module System. The connections between customer context and technical solutions are under the scope in the later BfP steps. (Pakkanen 2015, p. 195)

5.4.5 Step 5: Preliminary product family description

In the fifth step the objective is to get a preliminary description about the product family. For the description a modification of the Product Family Master Plan (PFMP) originally invented by (Harlou, 2006) is suggested. In PFMP the emphasis is on customer, engineering and part views. (Pakkanen et al. 2016, p. 226)

The customer view of the product family includes the most important customer need categories. Here the generic elements are in engineering view and part view includes assemblies and parts. An illustration of modified PFMP is in Figure 30.

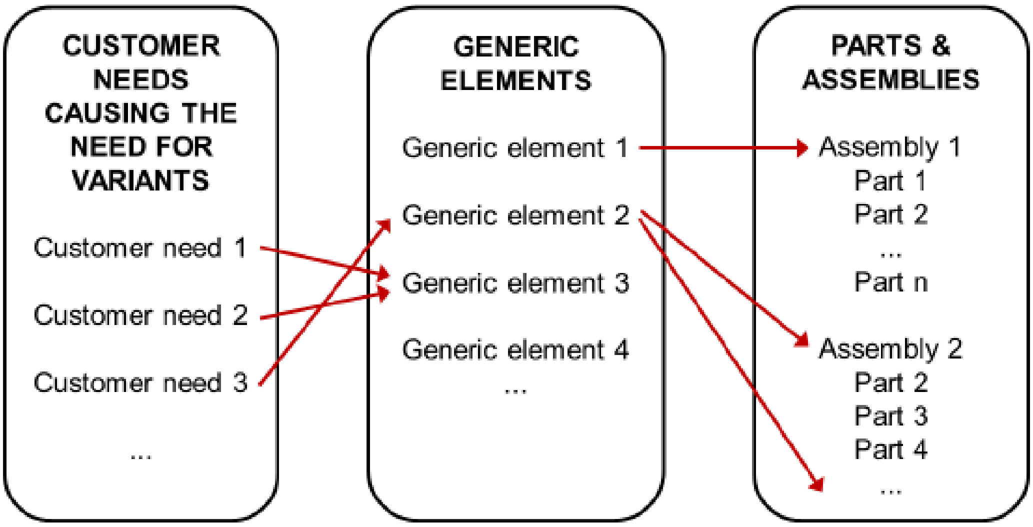


Figure 30. *A modified PFMP according to Pakkanen (2015, p. 197)*

The generic elements that are connected to several customer needs are a challenge for the BfP. If there are the same customer needs for multiple generic elements, the division of the elements might need more iteration. The generic elements that do not relate into any customer need are potentially standardized. (Pakkanen et al. 2016, p. 227)

The information about the types of generic elements (standard, configurable and unique) is included into the partitioning logic according to the definition of partitioning logic in Chapter 5.4. In this step the focus is on finding the ways to increase commonality level among the product family (Pakkanen 2015, p. 199). The output of the step is the preliminary product family structure with customer, engineering and part views (Pakkanen 2015, p. 199). The step connects to the partitioning logic and set of modules in the context of Module System (Pakkanen 2015, p. 199).

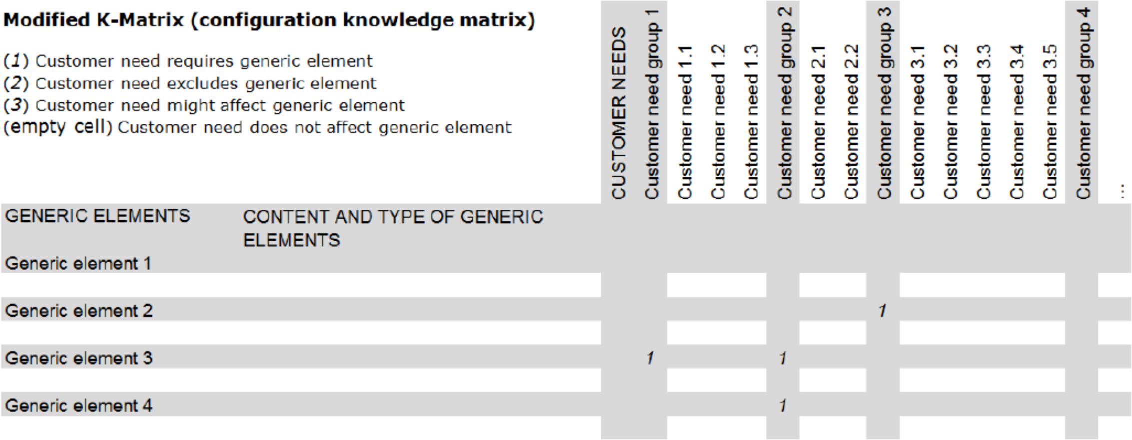
5.4.6 Step 6: Configuration knowledge: generic elements and customer needs

This step considers the customer needs connected to the generic elements that is the main part of the configuration knowledge. The detailed understanding of configuration knowledge is crucial when designing modifications, updates or even new product families. Modeled configuration knowledge is useful for implementation of the configurators of sales-delivery process. (Pakkanen 2015, p. 199)

For this step Pakkanen (2015) suggests a modified K-Matrix that is part of the K- & V-Matrix discussed by Bongulielmi et al. (2002). The original K-Matrix considers the relationships between technical view and customer view only by yes or no markings. In BfP due to the preliminary phase of technical view, more description is needed for relations. BfP suggests following statements to define relationships between customer requirements and generic elements:

- Customer need requires generic element (1)
- Customer need excludes generic element (2)
- Customer need might affect generic element (3)
- Customer need does not affect generic element (empty cell)

The numbers and empty cells after the descriptions are exploited in an example template of K-matrix in Figure 31.



Modified K-Matrix (configuration knowledge matrix)

(*1*) Customer need requires generic element
(*2*) Customer need excludes generic element
(*3*) Customer need might affect generic element
(empty cell) Customer need does not affect generic element

GENERIC ELEMENTS	CONTENT AND TYPE OF GENERIC ELEMENTS	CUSTOMER NEEDS	Customer need group 1	Customer need 1.1	Customer need 1.2	Customer need 1.3	Customer need group 2	Customer need 2.1	Customer need 2.2	Customer need group 3	Customer need 3.1	Customer need 3.2	Customer need 3.3	Customer need 3.4	Customer need 3.5	Customer need group 4	...
Generic element 1																	
Generic element 2										*1*							
Generic element 3			*1*				*1*										
Generic element 4							*1*										

Figure 31. *K-Matrix according to Pakkanen (2015, p. 201)*

Generic elements are in the rows and customer needs are in the columns in Figure 31. The modified K-Matrix is used in the later steps of the BfP to define the final configuration knowledge. Here the configuration knowledge stays on more abstract level. (Pakkanen 2015, pp. 200-201)

As a result of this step there is a description about relations between specific customer needs and generic elements. It supports the steps 7 and 8 where modules, interfaces and configuration knowledge are defined more in detail. According the Module System elements, this step considers configuration knowledge. (Pakkanen 2015, p. 201)

5.4.7 Step 7: Modular architecture: modules and interfaces

In this step, modules and interfaces are defined in detail. Defined modules and interfaces support the architecture consideration. Generic elements are clarified by dividing them by their types: standard, configurable, partly configurable and one-of-a-kind. Standard elements stay the same in every variant among the product family. In the case there are no variation need from customer point of view for a generic element and it can be realized by one technical solution it is potentially standardized as described in Chapter 5.4.5. Configurable elements are built of standard variant options. Partly configurable generic element is needed if there cannot be found reasonable number of standard elements for it. It means that the result consists of standard, configurable and one-of-a-kind elements. One-of-a-kind elements are used only in the cases if standard or configurable elements cannot be used in some part in the product family. (Pakkanen 2015, pp. 202-204)

It is important to concentrate on the product family's architecture and not only try to find solutions for individual needs of variations. The number of standardized elements can be increased by dividing generic elements into smaller pieces. The disadvantage of plenty elements is the increased number of interfaces that require management. An example of generic element division is illustrated in Figure 32.

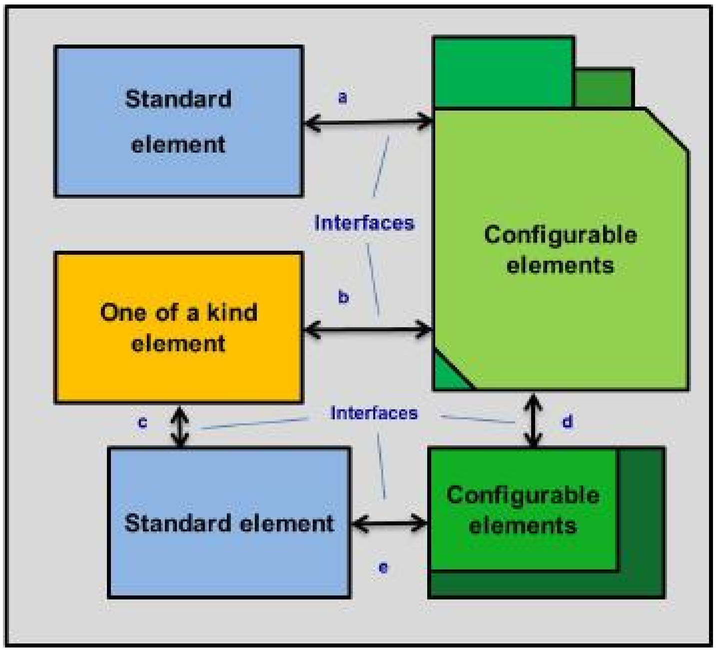


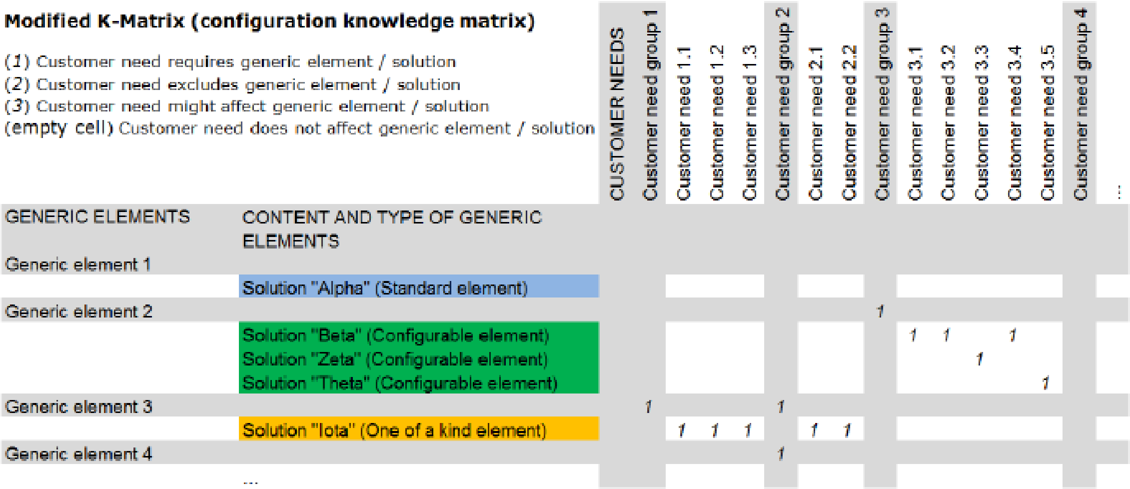
Figure 32. An architecture example of generic element according to Pakkanen (2015, p. 206)

It is beneficial to remain the architecture by avoiding changes in generic element division and standardize the interfaces between elements. (Pakkanen 2015, p. 206)

The importance of this phase for an architecture is emphasized. The architecture defines the elements and interfaces among the product family. The result of this step is needed later for the final configuration knowledge. The step considers architecture, modules and interfaces in the context of Module System. (Pakkanen 2015, p. 207)

5.4.8 Step 8: Configuration knowledge: module variants and customer needs

This step defines the configuration knowledge. The modified K-Matrix introduced in Chapter 5.4.6 is used again in this step. Here the content of generic elements is included into the consideration. The generic element types and their contents were defined in Chapter 5.4.7. The K-Matrix with detailed generic elements is illustrated in Figure 33.



Modified K-Matrix (configuration knowledge matrix)

(*1*) Customer need requires generic element / solution
(*2*) Customer need excludes generic element / solution
(*3*) Customer need might affect generic element / solution
(empty cell) Customer need does not affect generic element / solution

GENERIC ELEMENTS	CONTENT AND TYPE OF GENERIC ELEMENTS	CUSTOMER NEEDS	Customer need group 1	Customer need 1.1	Customer need 1.2	Customer need 1.3	Customer need group 2	Customer need 2.1	Customer need 2.2	Customer need group 3	Customer need 3.1	Customer need 3.2	Customer need 3.3	Customer need 3.4	Customer need 3.5	Customer need group 4	...
Generic element 1																	
	Solution "Alpha" (Standard element)																
Generic element 2										*1*							
	Solution "Beta" (Configurable element)										*1*	*1*		*1*			
	Solution "Zeta" (Configurable element)												*1*				
	Solution "Theta" (Configurable element)														*1*		
Generic element 3			*1*				*1*										
	Solution "Iota" (One of a kind element)			*1*	*1*	*1*		*1*	*1*								
Generic element 4							*1*										
	...																

Figure 33. K-Matrix with generic elements and their contents according to Pakkanen (2015, p. 209)

This step is needed to specifically recognize which technical solutions match the certain customer needs. The gained understanding about configuration knowledge is beneficial for sale-delivery process definition. (Pakkanen 2015, pp. 208-209)

The knowledge from this step can be exploited when building a sales configurator considered in Chapter 5.1.9. For sales configurator the compatible solutions need to figure out. In the sales configurator an option can exclude other options and a sophisticated sales configurator leads the customer to choose only technically possible combinations. (Pakkanen 2015, pp. 209-210)

The result of this step are the compatible technical solution and customer need pairs. If the step reveals lack in recognition of customer needs, there might be need for iteration. In the Module System context, the step considers configuration knowledge. (Pakkanen 2015, p. 210)

5.4.9 Step 9: Product family documentation

Before this step the modular product family is created. The BfP suggests documenting the results after every step. In this step the created product family is documented separately. The aim of the step is to describe the created product family and present the relations between customer needs and technical solutions. The BfP suggests the Product Structuring Blue Print (PSBP) documentation method. The principle of the PSBP is illustrated in Figure 34.

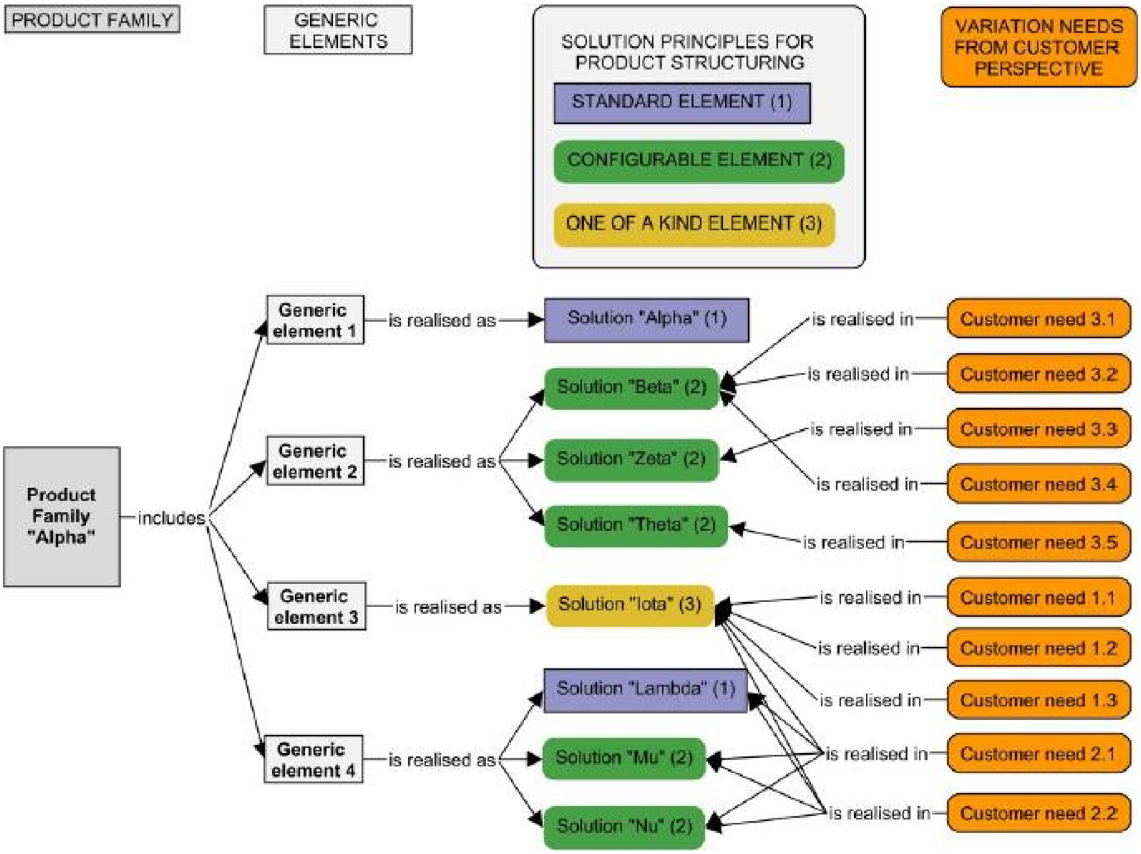


Figure 34. *Documentation by PSPB principle according to Pakkanen (2015, p. 212)*

In Figure 34 the created product family is on the left. The product family is divided into generic elements that further have the realized solutions. These solutions are finally linked with the corresponding customer needs on the right side. (Pakkanen 2015, pp. 211-212)

Documentation of the product family and reasons behind the decisions is important. The documentation visualization eases the design work and increases the level of re-used solutions. Documentation is also valuable in the cases when the product family needs changes. This step considers partitioning logic in the context of Module System. (Pakkanen 2015, p. 212)

5.4.10 Step 10: Business impact analysis

The aim of the final step of the BfP is to evaluate business impacts of the process. It considers how well the new product family meets the objectives that were defined in the beginning of the process. Additionally, the step evaluates the competitiveness of the created product family. (Pakkanen 2015, p. 212)

For the business impact analysis, the BfP suggests a method described in Figure 35.

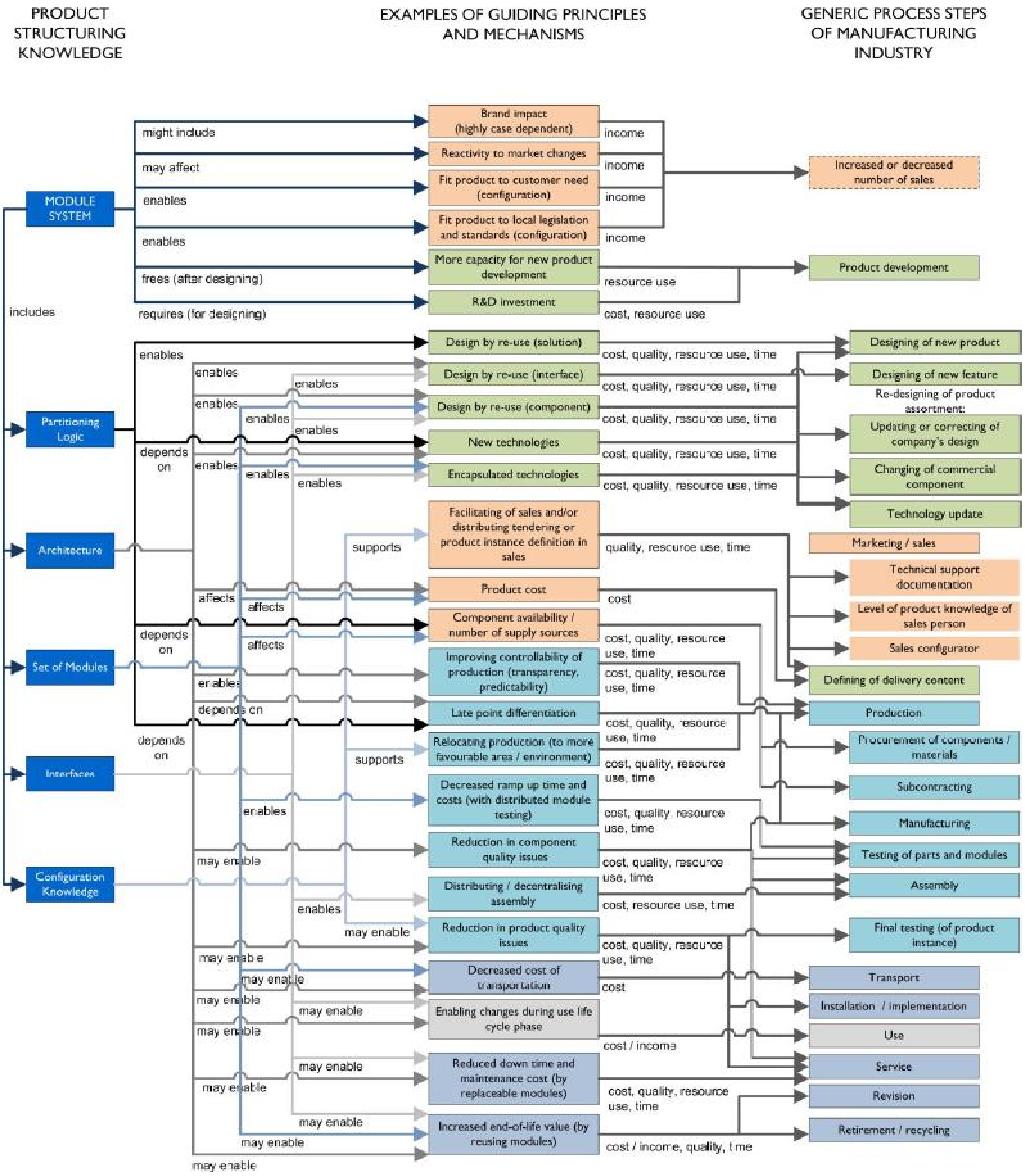


Figure 35. *Business impact analysis model in the context of Module System according to Pakkanen (2015, p. 215)*

In the left side in Figure 35 the elements of Module System relate to the guiding principles and mechanisms that can have impacts for modularity. Every BfP step is intended to increase knowledge about the Module System elements defines in Chapter 5.4. Guiding principles and mechanisms refer to objectives, phenomena and problems that may exist. There are similarities between guiding principles and module drivers considered in Chapter 5.3.3. The guiding principles and mechanisms include positive and negative impacts of the modularization. Further the impact of guiding principles and mechanisms for generic process steps of manufacturing industry is described in the right side. These mean for example product development, marketing, sales, production, transport, installation and use. (Pakkanen 2015, p. 214)

Figure 35 also considers the relation types among guiding principles and process steps; cost, quality, resource use and time. Some of the impacts are assumptions, not all exist there and some of them are not easy to measure. BfP suggests using “decades” (thousands, tens of thousands etc.) for measuring money. By this division only the largest impacts can be considered and measured in detail when necessary. (Pakkanen 2015, pp. 220-221)

The aim of the analysis is to proceed for the whole product family. In a case that the product family includes variable characteristics there can occur challenges on the analysis. Some of the variants can source opposite business impacts and the analysis can turn out to be useless. If that happens one approach is to divide the product family into pieces and make the analysis separately for them. The result of that can source changes for the partitioning logic and architecture. (Pakkanen 2015, pp. 221-222)

This chapter consists the theoretical background of the thesis that supports the case study. Main topics and definitions are described here. Chapter 5.1 describes the PLM concept and how product related data is managed by product structures and configurators. Chapter 5.2 presents the main modular product related definitions. Chapters 5.3 and 5.4 describe modularization work theories. The theories create the base for modular product specific PLM system needs. This thesis identifies the needs and finds solutions for them in the context of the case company.

6. CASE COMPANY

This chapter introduces the case company and the case. First the common information about the company and its products is presented. Previous modularity studies and the current modularity activities are examined. Here the modeling methods are introduced and evaluated. IT systems and their roles are discussed in the context of product data management and configuring.

6.1 Case company introduction

The case company operates globally on aggregates, mining, process industries and recycling and it is one of the leading industrial companies on these fields. In mines, case company's solutions are being used for processing minerals for all types of industry and consumer goods needs. In quarries, case company's solutions are used to produce aggregates for use by the construction industry. The term *aggregates* refer to crushed stone, gravel and sand at their natural or processed state. The offering of the case company consists of equipment, spares and service solutions and consumables for example, wearing parts.

Conveyors that are used to move material are commonly utilized among the case company's products. Due to the commonality in a product range a conveyor is used as an example product in this study. There is more detailed information about the conveyors in Chapter 6.3.3.

6.2 Modularization activities

The starting point of a modularization should always be a change in operation philosophy of how the commodities are produced. Modularization is a cultural change in a corporation. Wide-scale modularization is always a risk for a company. On the other hand, modularization is needed due to the recent developments in technologies, digitalization, pressure from changes in legislation to develop products and competitors investing on research. Due to these factors it is mandatory for the case company to implement modularization activities.

6.2.1 Modularization study objectives

One of the main objectives for the case company is to shorten the time to market. Successful modularization activities enable time savings on many levels. When design work focus on module designing there is no need for new product development in a way that is described in Chapter 6.3.1. Designing of smaller entities is faster and improves quality when the designing work has an existing and functioning solution as a basis. Time savings in designing are also achieved when the amount of product entities is smaller in the context of designing. The aim is to reduce the amount of tailored individual deliveries.

This will free labor from less profitable design work. The result of a successful modularization is a customer that will have more options to choose. At the same time the number of individual components is intended to be smaller.

The cost reductions and scale advantages are to be achieved by using common modules. In the case company the objective of shorten time to market will be achieved by new allocation of resources, standardized tests for modules and flexible production. The aim is to get uncomplicated assembling in separate module workstations and then assembling the modules with each other's.

The cost reduction is tried to achieve over the lifecycle by reducing the item count. Currently there are tens of thousands of unique items in the product assortment under the scope of the research, so the objective is to reduce the number of items significantly. The savings are to be achieved in data management when there is less time needed for inventory management and maintenance of the items. By smaller number of items, the case company tries to get savings in procurement where there are less unique parts from fewer suppliers. Logistics is intended to be more straightforward. The required time for documentation, communication, inspections and to solve errors aims to reduce. Further the savings are tried to achieve in production where there are fewer needs for changeovers, simpler production control, improved quality and reduced assembling and tool costs. Fewer items means ease in after-sales service by better availability and less time to train service engineers.

In addition to cost savings, smaller number of spare part items makes the products more attractive for the customers. Cheaper and better available maintenance components reduce costs and reduces the burden on warehousing. An objective is to achieve more income in after-sales service by compatible modules and standard interfaces over product family generations.

6.2.2 Current state of the modularity studies

The previous modularity activities in the case company have been closely related to the specific products or product families instead of IT system perspective. The aim in previous activities has been in standardizing and following customer requirements when designing product entities. Currently about 70 % of the product deliveries are standard products. One of the previous researches is focused on design methods and best practices but it does not take a stand about management of product data.

Today the product data quality and coherency are actively measured in the case company, and product information management has been unified more globally. The division of responsibilities of a design work is also globally unified. The utilized design tools are standardized among the corporation. The recognition of modules has been in the case company for decades, but the module philosophy needs to be updated. The architecture, module and an interface need to be defined in a new way to suit the company.

There have been major improvements in the IT system capabilities after the previous researches. Teamcenter rich client and Teamcenter Active Workspace have been recently updated in the case company. Siemens NX is also updated to the latest version. The case company introduces a new architecture management tool. A design library for screws, nuts and washers is created and deployed into Teamcenter. In the future the design libraries will be created for other entities too. The design libraries enable to make sure that the applied components in the structures are updated and physically available for the manufacturing and assembling departments. The deployment of design libraries are also the first steps to standardize components and decrease the number of items in the future. The design library is one possible option to store modularity related objects down the line, such as for modules and interfaces.

6.2.3 Intended changes among the study

The required change mainly affects the way of operating and the corporate culture but here are couple of examples about the practical changes in the case company. Research and Development phase will be enriched by considerations of after-sales service. Therefore, the case company will respond more efficiently to the demand in service business. The measurement tool for product quality will remain unchanged. New indicators will be established for item number count and the number of introduction items.

There is an intention to enlarge product structure recognition. There will be separate structures for engineering, manufacturing and service. This is a result of different information needs about the product structure. Engineering BOM (eBOM) and manufacturing BOM (mBOM) are described more in detail in Chapter 5.1.7

The architecture management tool controls the sales configurator and the product structure configurator in the future. The starting point for configuration process has traditionally been a general product model. In the future the configuration process will be structured purely from the module assortment and not based on any specific product model. By this way the configuration process is intended to be more straightforward compared to the current. After introduction of the architecture management tool the new combination of IT systems will go through a blueprint and proof of concept (PoC) phase.

6.2.4 Risks of modularization activities

Modularization requires a lot of resources which is a challenge for any company. The main risks for the case company relate to costs and schedules. The new design method of the products can become too expensive compared to the competitor’s products in the markets. Many companies have modularization done only for some parts of the product assortment. This is a risk for the cultural change if the production methodology varies among the assortment. The new culture needs to reach all the branches in the corporation.

The new combination of IT systems will source risks. The information needs to be in a required format to reach the desired systems on time. There are going to be new challenges due to the new IT systems. The handling of a new and more complex IT architecture can become laborious.

6.3 Modeling methods for a modular product

Here, the reasons for the case approaches and assumptions are indicated. Also presented are the future possible modeling methods. Considerations about usefulness about the methods and their compatibility are described in the following sections.

6.3.1 Past designing methods

In the past, the methods of design work have evolved over time and there are many variations in the solutions in the case company. Traditionally the development work is done by new product development (NPD). In the case company it means that the whole product entity was designed from scratch. This methodology is too laborious and the time to the market is too long. The products have become more and more complex, so the method is no longer efficient. The designing methods vary among history which makes integration of different solutions difficult. Product testing for complex products is not easy to implement and quality issues may arise in a late phase. The quality issues in these cases can be difficult to solve and scheduling of product launches are not easy to predict. In addition to standard products a lot of tailored products have been designed and it has committed resources.

The product range has expanded, and the number of items has increased. Traditionally there have not been strict rules or common practices for design. Recently the level of standardization in design work has increased, and the sharing of knowledge has become more sophisticated. For example, internal training and best practice documentation has been implemented concerning design work.

6.3.2 Baseline for the practical study

Currently the recognition of modular products in PLM and CAD is not very sophisticated in the industry. There are no standard methods existing for modular product management in the PLM and CAD environments. Variation in CAD software also is a challenge for general methods to integrate modularization tools into PLM and CAD. Multiple IT system combinations affect variation among different companies for modular data management methods. Companies exert a lot of effort to get the best mixture of software and integration between them. In many cases the present IT systems are a burden when applying new modular design methods for a company. Standardized language for modular products is also missing so it makes communication difficult.

Modular products do not exist yet in the case company under the scope of the research. One of the biggest challenges is the variety of the product range. Standardization level in the products is currently low. Despite that the modularization and standardization is not applied extensively at the case company a lot of work to enable these has already done as described in Chapter 6.2.2.

In the case company there is no common language for modular products yet, and there is a demand for consideration of the kinds of terminology that will be used in the future. Currently the case company gathers information about methodology and terminology of modular product data management from literature and by updating IT systems. The creation of the methods is in an early phase and it will require a lot of iteration. The architecture management tool will cause limitations for the methods. The data management methods will be more fixed for Teamcenter compared to the detailed way of design in NX. The internal terminology of the case company will require updates.

6.3.3 Initial settings for the exercises

The scope for the practical research was initially limited to the IT systems. The architecture management tool for managing modular product were not available for the author during the time of the research. This challenge excluded the top-down approach for the research. Therefore, a bottom-up approach was implemented in the research. This means, that the consideration started in CAD and the modeling methodology was adapted to follow the requirements of the architecture management tool. To get an understanding about the modularization philosophy implemented in the architecture management tool meetings were arranged internally and with the CAD software provider. All the modeling exercises were modeled by Siemens NX.

As a result of the meetings and considerations a side conveyor was chosen for the research as an example. A conveyor is one of the most common functional elements in the product assortment and therefore most of the employees in the case company are already familiar with it. The objective was to identify the definitions for the product objects and create some suggestions and best practices based on the findings in the exercises. In the exercises the assumptions and limitations that concern the sub-components became detailed as the research progressed. All the exercise related limitations are defined in the exercise descriptions.

6.3.4 The first modeling exercise

In the research the recognition of the PLM elements started from identification of interfaces and modules in CAD environment. The scope of the modeling exercise was limited only to mechanical interfaces. Modeling interfaces and modules started with consideration about the chosen component entities. At the beginning a belt conveyor was chosen as a modeling starting point. One of the conveyors under consideration is illustrated in Figure 36.

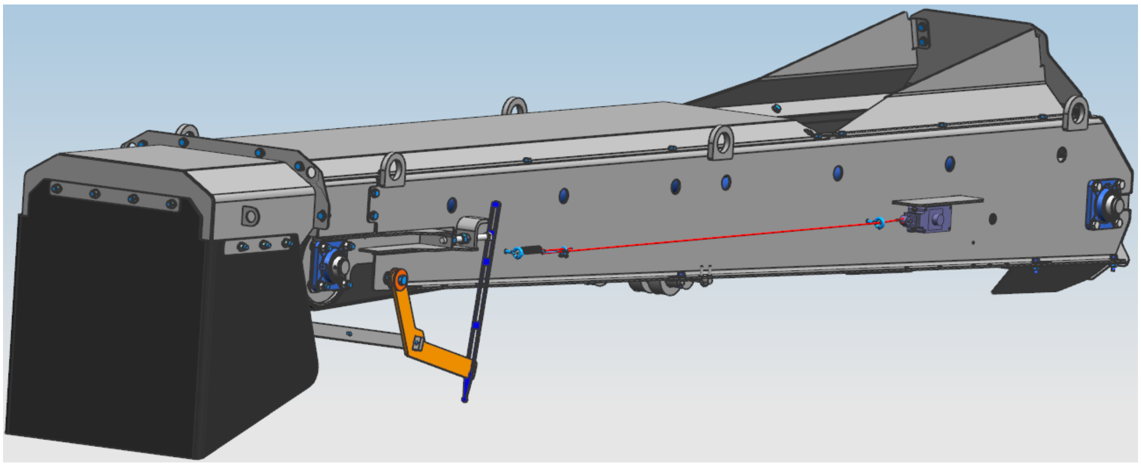


Figure 36. *One of the five belt conveyors*

At first five different conveyors with similar functionalities were chosen for this scope. It later turned out that there is excessive variation among the conveyors to evenly divide them roughly into modules or recognize common interfaces between the modules within the limits of research resources. Also, the structures among the conveyors vary. Simplicity was one of the MFD aspects described in Chapter 5.3.2. For these reasons, the chosen components were later limited into drive devices of the five conveyors. Figure 37 shows one of the drive drums.

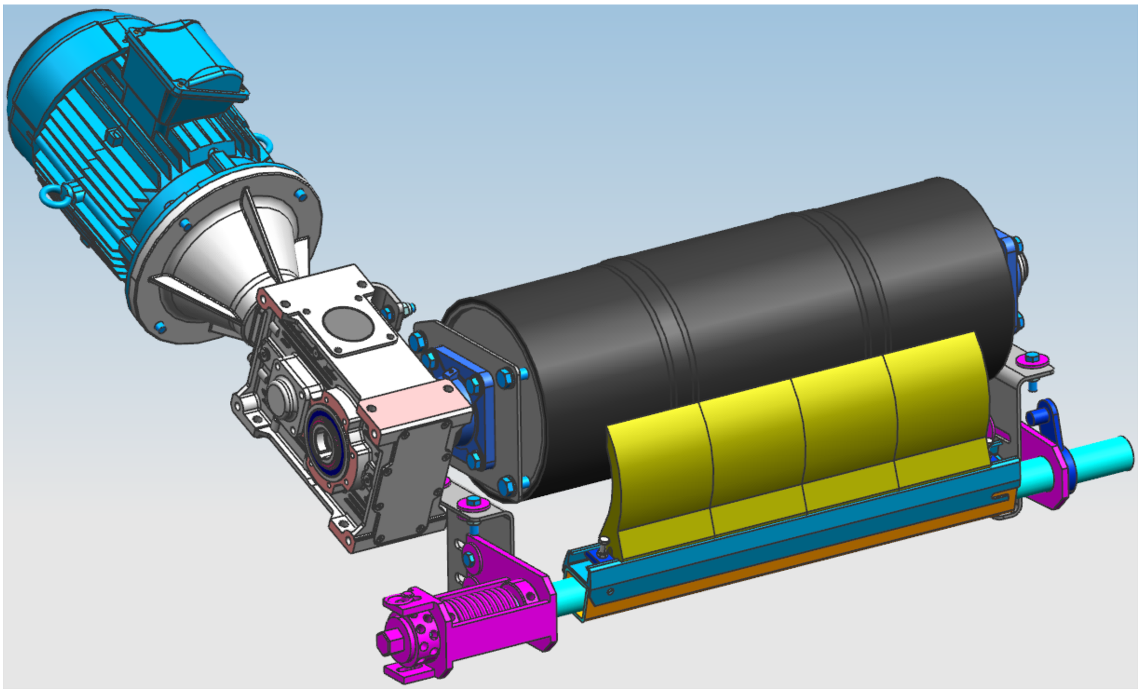


Figure 37. *An electric drive device for conveyor*

Modularization activities for conveyors will be implemented later in the company.

There are two main types of drive devices: hydraulic and electrical. This strongly affects the drum and the shaft types. Electrical conveyors are additionally attached into the frame by moment support. There is a lot of variation also in the bearings and their attachment types into the conveyor frame. An electrical drive device has two bearings in the shaft ends but a hydraulic drive device has a bearing in the one end and the motor is in the other end integrated into the shaft. Variation in dimensions drive drum’s diameter and width to make changes to the interfaces and their positions. An illustration of the variation among the five drive devices is illustrated in Figure 38.

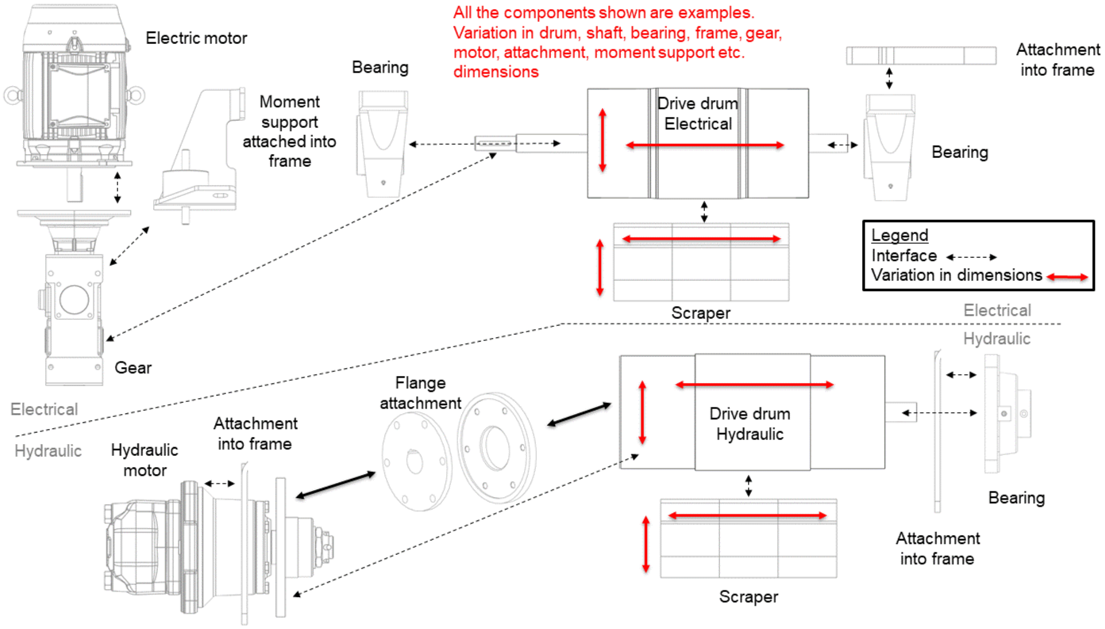


Figure 38. *Starting point in modeling interfaces and components among drive devices*

As can be seen in Figure 38 there is a lot of variation among the drive devices so it is challenging to find common interfaces between all the components among the drive devices.

In this exercise interfaces are modeled as sketches and sheet bodies. The definitions for interfaces are described in Chapter 5.2.4. Every interface is an item and it is inclusive of any physical entities. For similar interfaces with different dimensions so called part-families are created. There is more part-family consideration for interfaces in Chapter 6.3.6. There is a master interface for the interface that owns all the interface family members. Only the interface family members are used for individual cases. In this example, different size of flanges with similar shape are used to attach drive drums and hydraulic motors. There is an interface master which owns all the interface variants for this flange attachment. The assumptions regarding interfaces was made after discussions with the CAD software provider. There is an example about flange attachment between physical parts in CAD software in Figure 39.

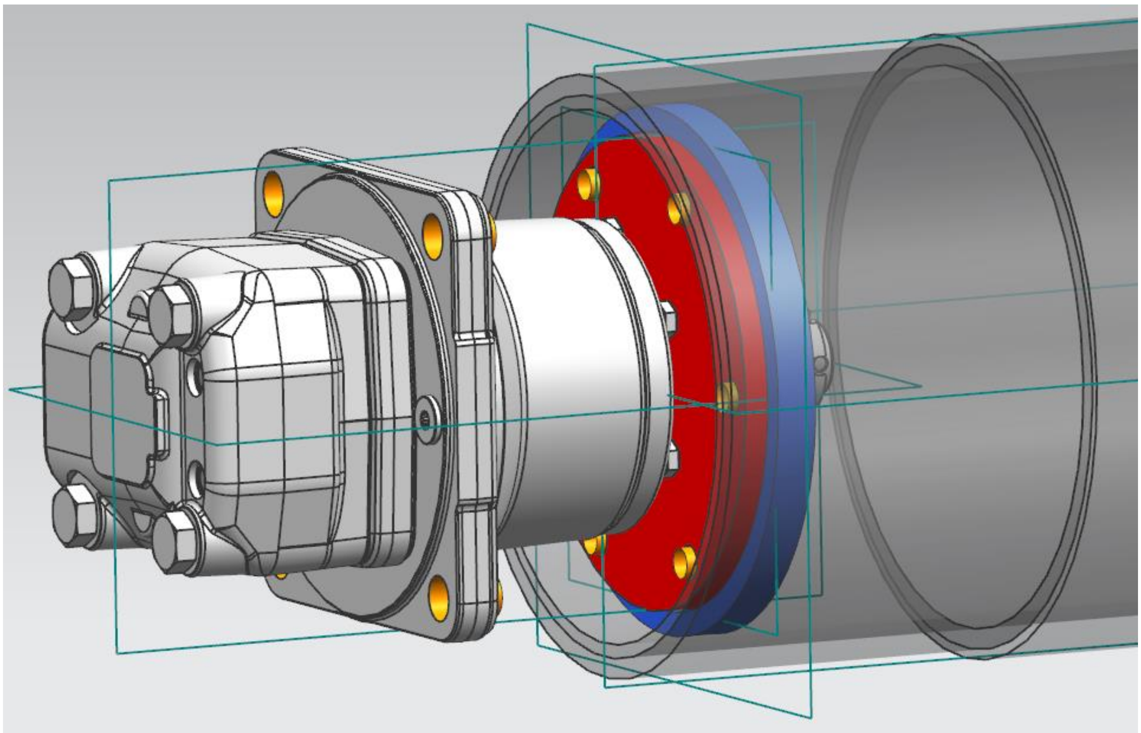


Figure 39. *Flange attachment between a drive drum and a hydraulic motor*

In Figure 39 the interface is between components that are marked in red and blue. In this case the interface is recognized by the coordinate system, blue sketch lines and orange sheet bodies as can be seen in Figure 40. In the simplest case the interface is recognized only by a coordinate system. The coordination system is added to the main level of the assembly and constrained to the wanted location. This approach can be used in a case when there is no physical module for the interface to be attached.

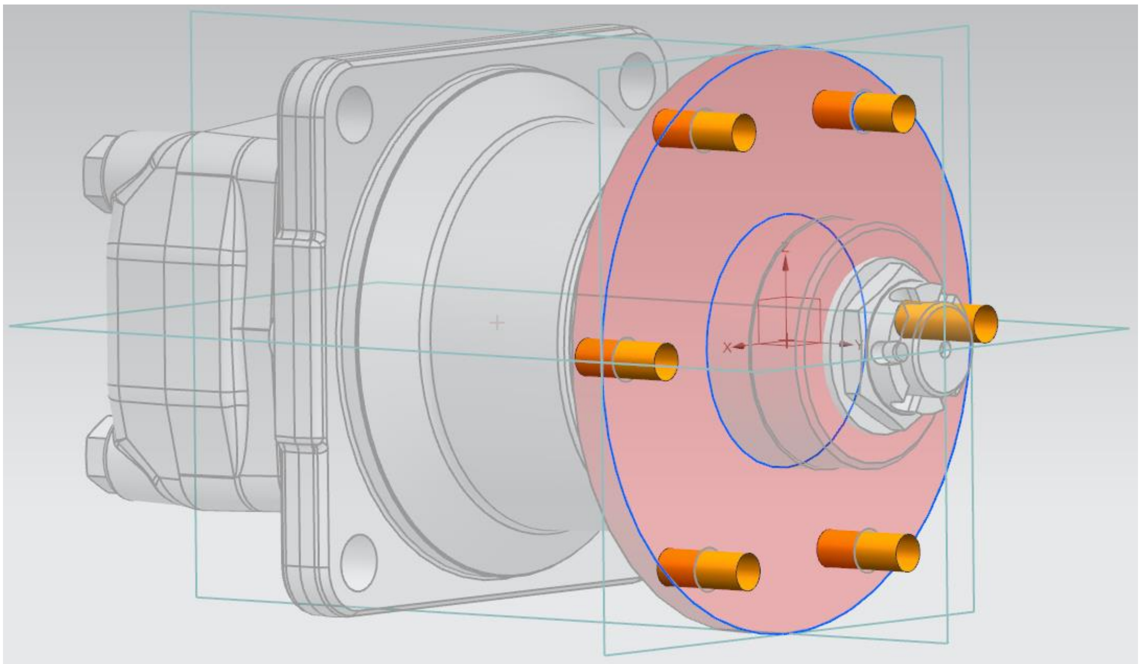


Figure 40. *Interface in a hydraulic motor*

In this example the same interface item is added for the hydraulic motor and for the drive drum. The interfaces in the hydraulic motor and in the drive drum are constrained by the coordinate systems. In Figure 41 an example of a part family for interfaces with three different variants is illustrated and the smallest variant is highlighted.

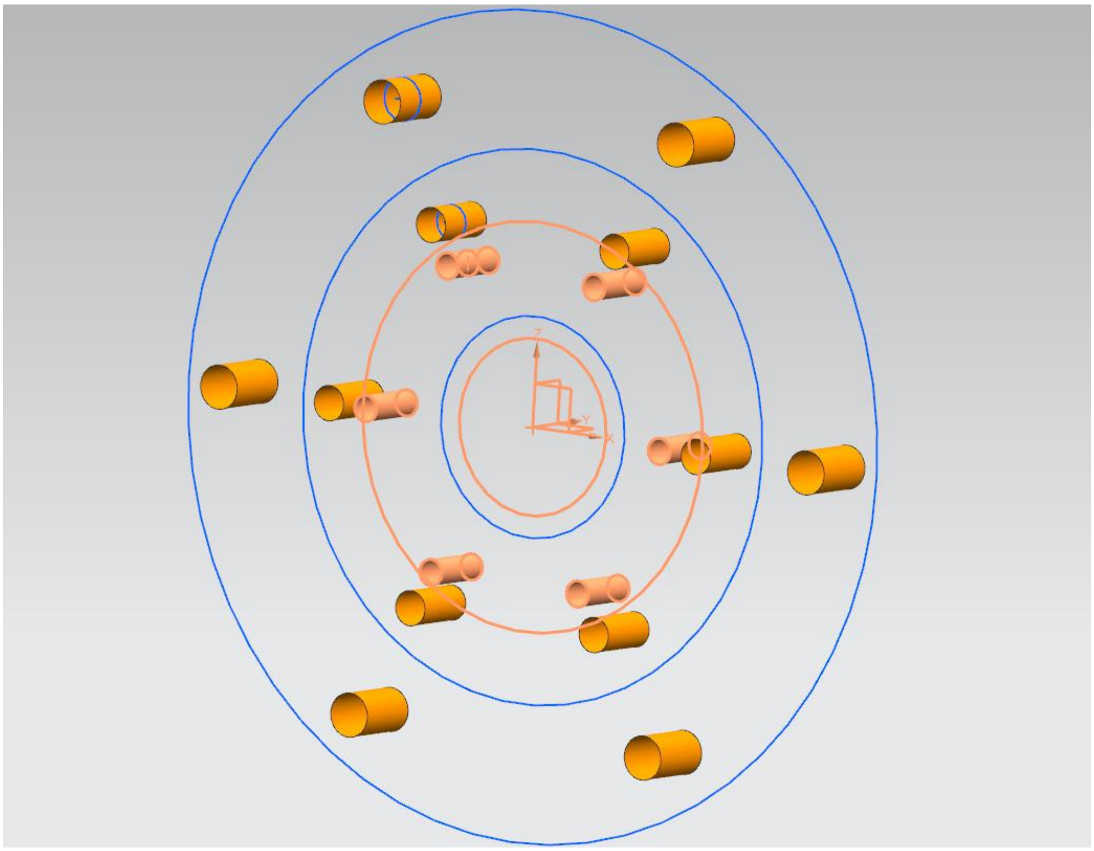


Figure 41. *Three different interface instances in an interface part family*

In this example first the drive drums were placed and constrained to the assembly coordination system. Interfaces were added for all the components; drive drums, hydraulic motors, hydraulic motor supports, bearings, bearing supports and a scraper. These components were constrained by using the interface items inside the components.

The exercise did not enable further considerations because of the variations in the existing functional elements. It was not sensible to combine these components into a module system. The exercise was a good instruction for interface recognition in CAD and gave a lot of needed knowledge for the following exercises.

6.3.5 The second modeling exercise

The second modeling exercise did not regard the conveyor. This exercise follows the initial design methodology instructions for Siemens NX that will be a base for the future modeling methodology. The new modeling method contains many steps and it is different in many ways compared to the existing modeling method in the case company. The instructions on a practical level describe the modeling steps in detail. In this exercise only mechanical interfaces are considered. This exercise enables preparation for the following modelling exercise.

The modeling methodology follows the principles derived from MFD, and the practices serve a modular product structure. The focus of the instructions is on the architecture, product configuration, modules, interfaces and space reservations. A lot of supportive objects are used to achieve modular design that follows the change procedures and avoids unintentional changes. The purpose of the supportive objects is to keep on track the changes in the module system. The suggested and implemented modeling methodology in this exercise and in the third exercise is presented in Figure 42.

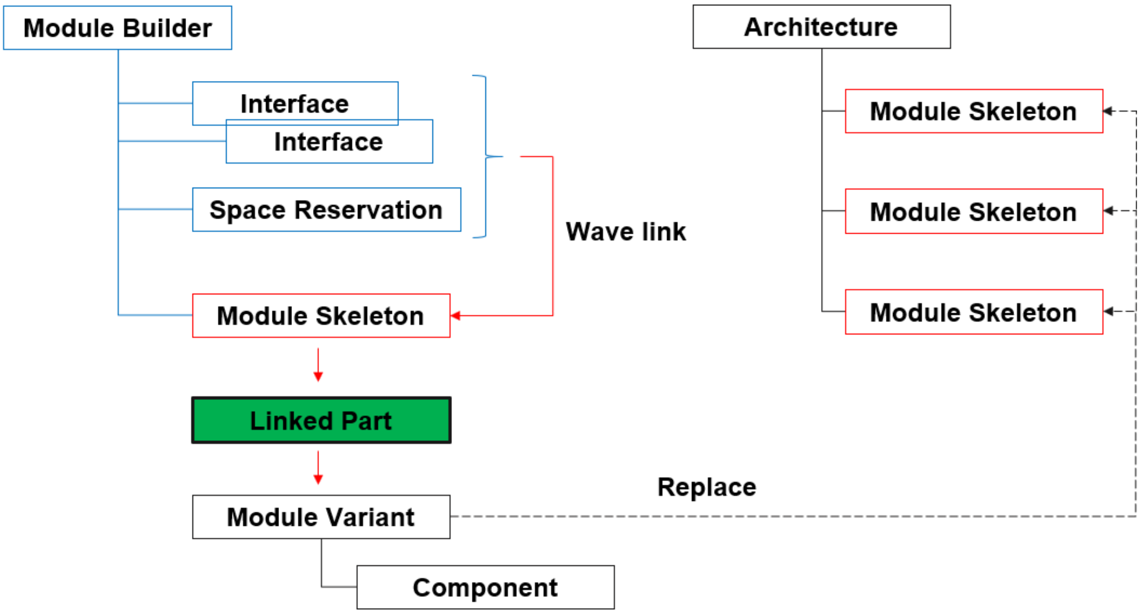


Figure 42. *Modeling methodology for a modular product in Siemens NX*

The focus of the methodology is on interfaces and space reservations. In any modeling phase the interfaces and space reservations are visible, so it helps the designer to respect them.

The modeling is intended to start by modeling interfaces and space reservations. These elements are combined into the "*Module Skeleton*" by "*Wave Geometry Linker*" tool in Siemens NX as can be seen in Figure 42. There can be several interfaces in a "*Module Builder*" respecting the attachments between different modules but only one "*Space Reservation*". Space reservations ensure that the modules will not interfere with each other.

The Module Skeleton is copied into Module Variant by using "*WAVE*" functionality in Siemens NX to create a "*Linked Part*". This functionality requires an extended license for Siemens NX. Module Variants include the physical design components. An architecture is an assembly that has all the Module Skeletons. By replacing the Module Skeletons in Architecture, the product individual is created. When creating the product individual, the configuration rules need to be followed.

According to the instructions several supportive elements are created before the physical module variants. Specific definitions for the applied design objects and model constructions are in Appendix D. In Figure 43 an interface and a space reservation are modeled before the actual module. As can be seen in Figure 43 the interface is modeled as a face with sides for male and female representations by blue and red colors respectively. In this case the female side is upwards, and the male side is downwards.

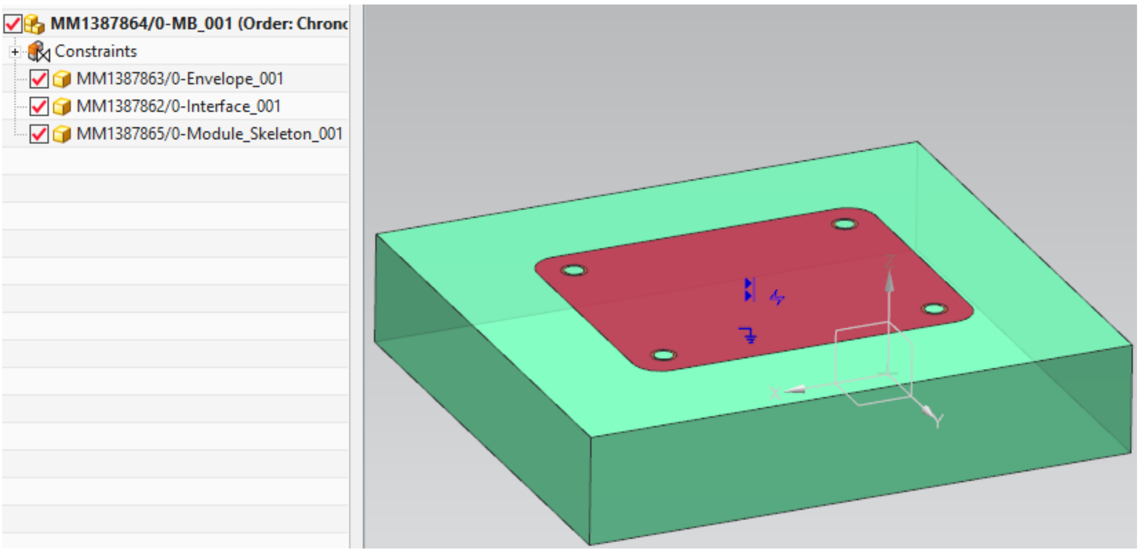


Figure 43. *An interface and a space reservation for a module variant*

By visualization space reservations and interfaces, it is easy to perceive the elements in a way that supports modular design work. The methodology requires rules for coordination system directions and constraints for the design objects. In Figure 44 all the module respective interfaces and space reservations for a product are illustrated.

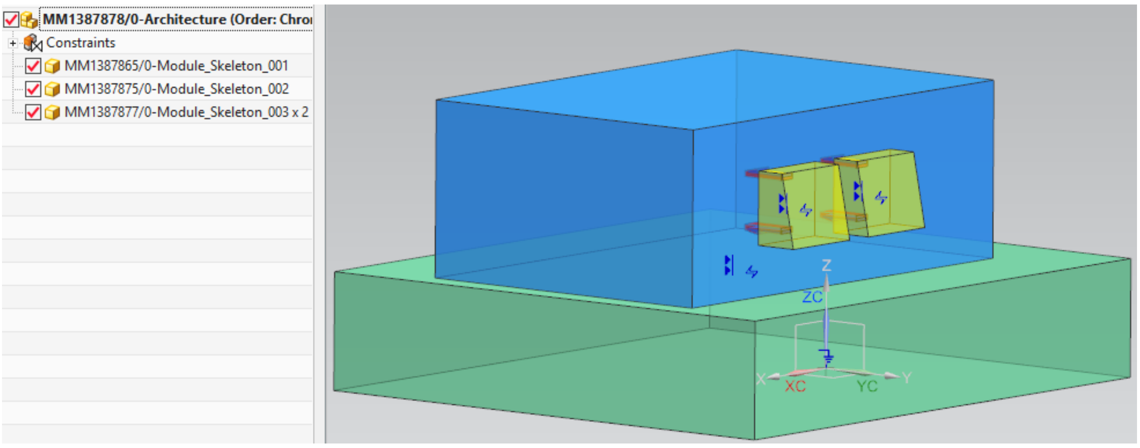


Figure 44. *Assembly for all interfaces and space reservations in a product*

The provided modeling methodology provides handling for all the product variants. It is beneficial to perceive the whole product consisting of all the modules so the predigested model with only the interfaces and space reservations is approached.

In the second exercise the understanding about space reservations concretized contrary to the first exercise where the emphasis was mostly in interfaces. The interfaces were also defined in a different way compared to the first exercise and here all the interfaces were made visible by solid elements but with a zero thickness as can be seen in Figure 43.

The suggested method is laborious and some of the steps seem unnecessary even though the method ensures traceability. There are also many applications that this instruction is not giving answers. The exercise gave a good starting point for the following meetings and it is also useful a base for defining the product elements in the IT systems especially in Teamcenter.

6.3.6 The third modeling exercise

The purpose of the third modeling exercise is to adapt the future modeling methodology for the case company's products. The exercise has the similar methodology as in the second exercise. This modeling exercise enables consideration of how the module objects will be entered to the case company's PLM system. Furthermore, the models are used as building links between the architecture management tool for modular product data management and the case company's CAD software. The exercise builds a suggestion base for management the modular product data in the different IT systems.

As observed in the first modeling exercise it was not useful for this research to use existing products as a starting point. After considerations this modeling exercise implemented by creating models loosely connected to the conveyors. The models are called "dummy modules". The scope of the modeling exercise was limited to the electrical conveyors. Only the mechanical interfaces are considered in this exercise. The preliminary module division is illustrated in Figure 45.

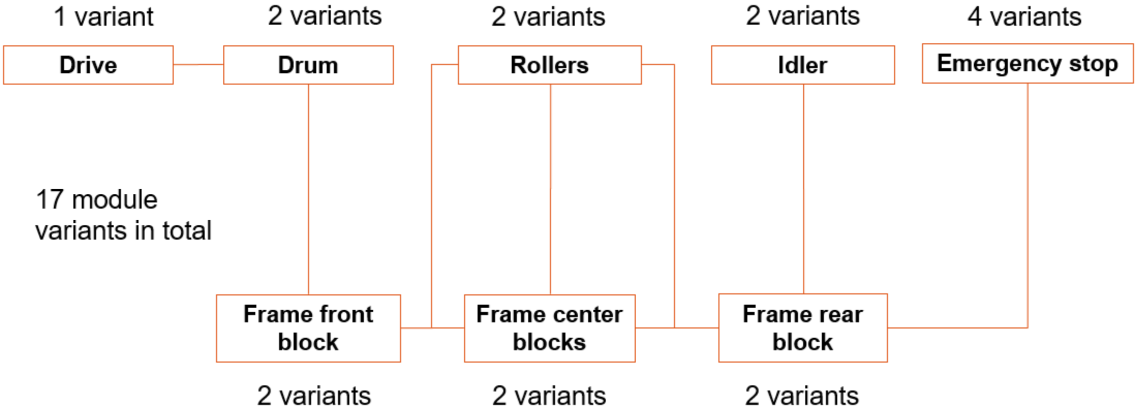


Figure 45. *Module division in the third modeling exercise*

The modules in the boxes are connected by lines that represent the interfaces between modules. In the exercise variant modules were made to achieve a final product with different widths for the drum, frame blocks, rollers and idler. The emergency stop has variants to adapt different widths and lengths of the conveyor. The conveyor frame was divided into blocks to illustrate variable lengths for the conveyor.

The models left on a coarse level due to the limited resources and especially respecting the fact that the module division is just an example and it is not considered according the MFD process. The modules are built up according to the methodology presented in the second modeling exercise. The module architecture in the exercise is illustrated in Figure 46.

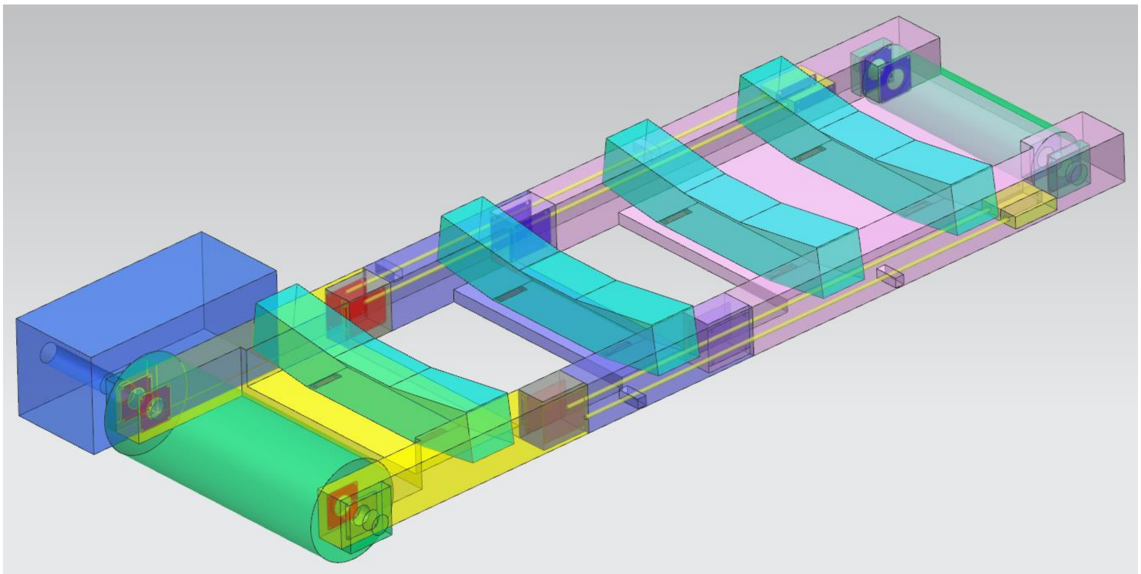


Figure 46. *Space reservations and interfaces for the modules*

The space reservations in the exercise are modelled to be able to illustrate the greatest possible dimensions among the module variants. Transparency is added for the space reservations to make the assembly clearer and to make the interfaces visible. All the interfaces have a male and a female representation as presented in Chapter 6.3.5 to keep on track about the required attachments in the modules. The architecture in Figure 46 is assembled by module skeleton elements. The module skeleton contains the information about the module's space reservation and interfaces. The module variants are easy to build up by replacing the module skeletons by the wanted module variants. For example, the "Module Skeleton Drum" can be replaced by "Variant Wide Drum" module variant. When all the module skeletons in the architecture are replaced by the variants the product configuration is ready.

Creation of conveyor results six different variants when the rules allow the attachments only with the modules with the same width categories and the lengths for emergency stops are fixed according to the length of the conveyor variant. The rules for length limit the number of center blocks from 0 to 2. In Figure 47 there are two different conveyor variants sourced from the architecture model by replacing the module skeletons with the module variants. The upper model in Figure 47 is narrower compared to the lower one.

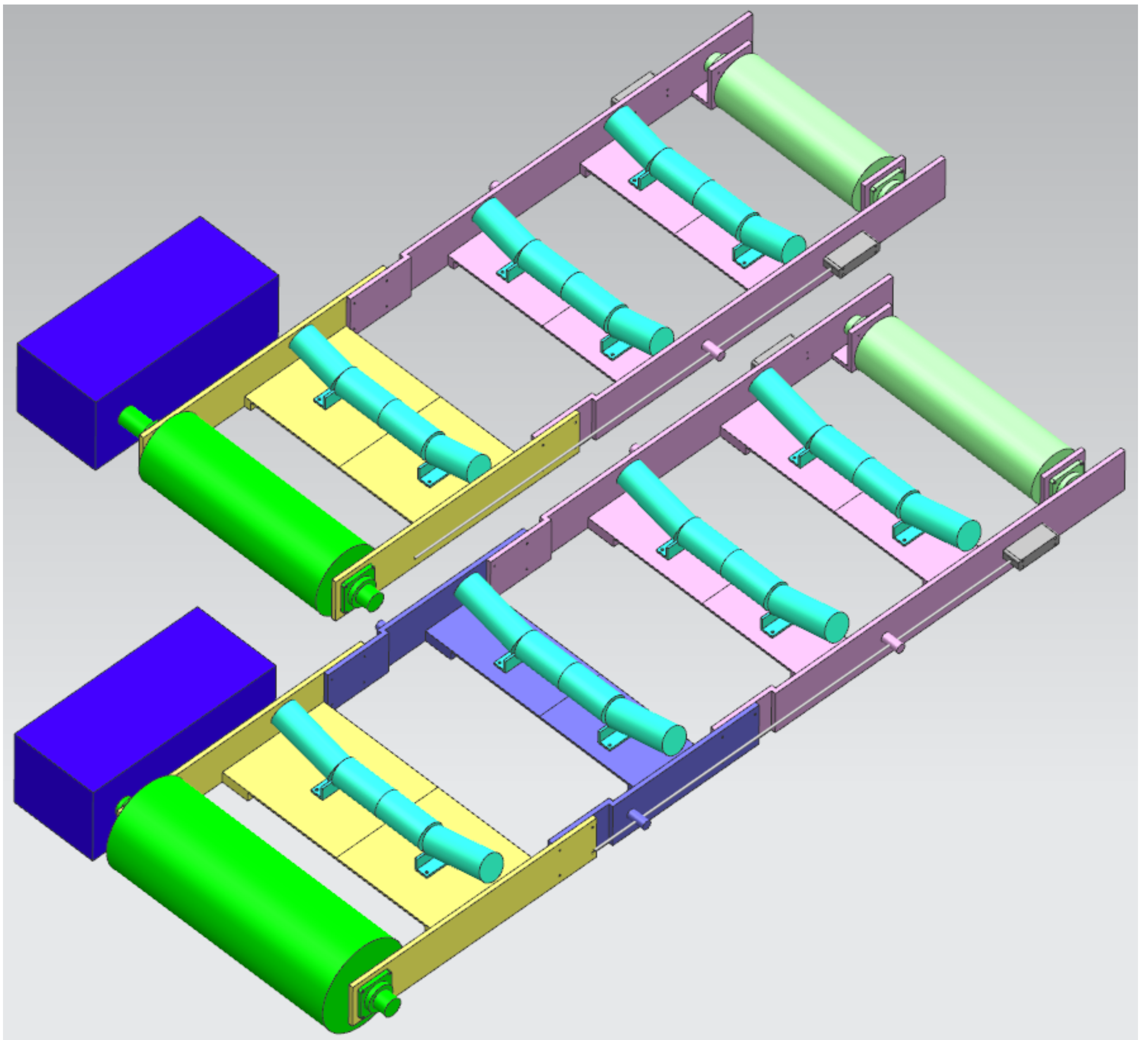


__Figure 47.__ Variant examples in the third modeling exercise

In the upper variant the front frame block is attached to the rear frame block without the central frame block to get a shorter conveyor variant. One option to get more flexible length variations for the conveyor is to make the central block's length continuously variable. By doing this, the number of the attached rollers needs to be connected to the length. The length and the number of rollers can be driven by expressions from the product structure configurator to CAD software. In a real case the flexibility in the architecture needs to be connected to the current or future customer needs as described in Chapter 5.3.1. Additional flexibility that is not serving customer requirements is not beneficial.

After the modeling exercise was done, it provided a greater understanding about the new modeling methodology. This turned out to require an extended license for NX to get the "wave links" made between the new modeling objects according to the methodology described in the second exercise. In the third exercise it got a bit quicker to get the models done after practice in the second exercise.

Still, the new modeling method was time consuming and confusing intermittently. The provided modeling instructions do not give answers for all the challenges faced during the exercise. For example, according to the instructions an architecture model is established but it is not obvious how to exploit the architecture model if the modules changes places with each other. The exploiting method for space reservations is not trivial. When the space reservation includes all the variants, then there overlaps appear between the space reservations. The usage of part families that was described in Chapter 6.3.4 cannot be used if the new modeling method is applied. After all the exercise turned out to be a vital base for the modular object comparison between the IT systems.

6.4 Product data of a conveyor in PLM

The conveyor modeled in Chapter 6.3.6 is considered in the context of the new architecture management tool. The modules are managed in the architecture management tool and the data from there is entered into PLM. In the case company the data is sent to Teamcenter. In Appendix A the conveyor is recognized in the architecture management tool on the left side and in Teamcenter on the right side. In Appendix A the purple and red color-coded elements have the corresponding objects according to the legend on the left. Module Nodes in the architecture management tool do not have matches in Teamcenter. Class instances can be found only in Teamcenter as they are the module variants.

The classifications in Teamcenter are important specially to ease searching of data. By classifications the data can be structured by hierarchy and re-use is easier. A classification that exists preliminary entered attributes lowers the possibility of mistakes. Re-use of design is one of the key factors when reducing the item count. Traditionally the usage of classifications for data has been limited in the case company.

The methodology introduced in Chapter 6.3.5 is in line with the PVM methodology described in Chapter 5.1.11. The modules are managed in the architecture management tool, but the data of module variants is stored only in Teamcenter. All the modules and variants are the same as the ones that were used in the third modeling exercise in Chapter 6.3.6.

6.5 Management of modules in Teamcenter

Teamcenter stores all the information about modules and interfaces. Module and interface specifications are attached to the respective items. These items can be handled by module and interface libraries in a similar way that is described in Chapter 6.2.2.

In Teamcenter there are four different ways to manage object control; object type, groups, roles and object status. The management of item statuses described in Chapter 5.1.6 is handled in Teamcenter in the case company. The item consists of different types of files and all are under the procedure of revisioning.

Currently there are already multiple ways to implement access management, for example by roles in Teamcenter and by different object types and exploiting their characteristics. The instances of part-families used in the first modeling exercise in Chapter 6.3.4 can be changed only by changing the part-family master. This can be a simple way to handle the architecture among the dimensions that vary as planned. By using part-families the access management can be handled without extra considerations and the possibility of a mistake is lower.

6.6 IT systems for data management

There is a complex set of IT systems for handling the product data in the case company. An approximation of the existing IT systems and key documents managed by them is illustrated in Appendix B. The IT systems are divided into four main categories; plan, create, sell and supply. This division is not strict and some of the systems can exist in multiple categories or between the categories. The role of the systems evolves constantly, and the impacts of systems can expand to the new categories or disappear when a new system takes the responsibility. Currently the sales configurator and product structure configurator are integrated, and it cause challenges for the case company. In Appendix B every system is marked only once.

Plan systems are mainly for decision makers, executive managers, managers, engineers, R&D (Research & Development) engineers and for product managers. Here, data comes into existence that leads all the product related information in the corporation. In the future the case company tries to increase the amount of feedback from systems in other categories to make more rationalized decisions in planning phase.

Create systems are mainly for engineering, production and service. Engineering includes also the subcontractors that works for engineering. Most of the product data creation is made in these systems. For these systems the number of users is the highest. There are many requirements for these systems and a small change can have unpredictable consequences if the number of users or the amount of data transfer increases.

Sell systems are for sales, after sales, marketing, sales support and further for customers. Here the customer related data, prices and data about market areas are managed. Marketing material and warranty issues are handled here.

Supply systems are supposed to serve production, service, supply, logistics and customers. The data is needed for subcontractors for example, to get the manufacturing drawings delivered. In these systems the most useful data for feedback is collected. The proper feedback is crucial to enhance quality in planning stage. The feedback from these systems is used all over the corporation.

The combination of IT systems will evolve a lot after the architecture management tool is applied into use in the case company. Due to the early stage a clear definition about the IT systems and their responsibilities in the future is not easy to estimate. An approximation about future IT systems in the case company based on interviews and a workshop with the company’s IT specialists is illustrated in Appendix C. The exact documents and ways of communication between IT systems is not included into Appendix C as they will evolve considerably soon. In Appendix C all the systems are marked once except Teamcenter to emphasize the wanted role for it in the future.

Teamcenter will manage product data more comprehensively and most of the systems will be connected into it. In the future sales configurator and product structure configurator will be separated and attached into Teamcenter. Currently Teamcenter has about 800 hundred users.

The main systems locate to the center area in Appendix C and the less important ones are on the sides. As can be seen in Appendix C the amount of wanted systems is decreased. The aim is to reduce complexity of data management. In the year 2023, the systems still be a bit scattered, but the aim is to increase the level of integration between systems. In 2028 ERP, PLM and MES systems are intended to have more sophisticated automated information transfer ways. The level of automated data transfer is not clear for the future and it is strongly dependent about investments into the systems.

6.7 Configuration work

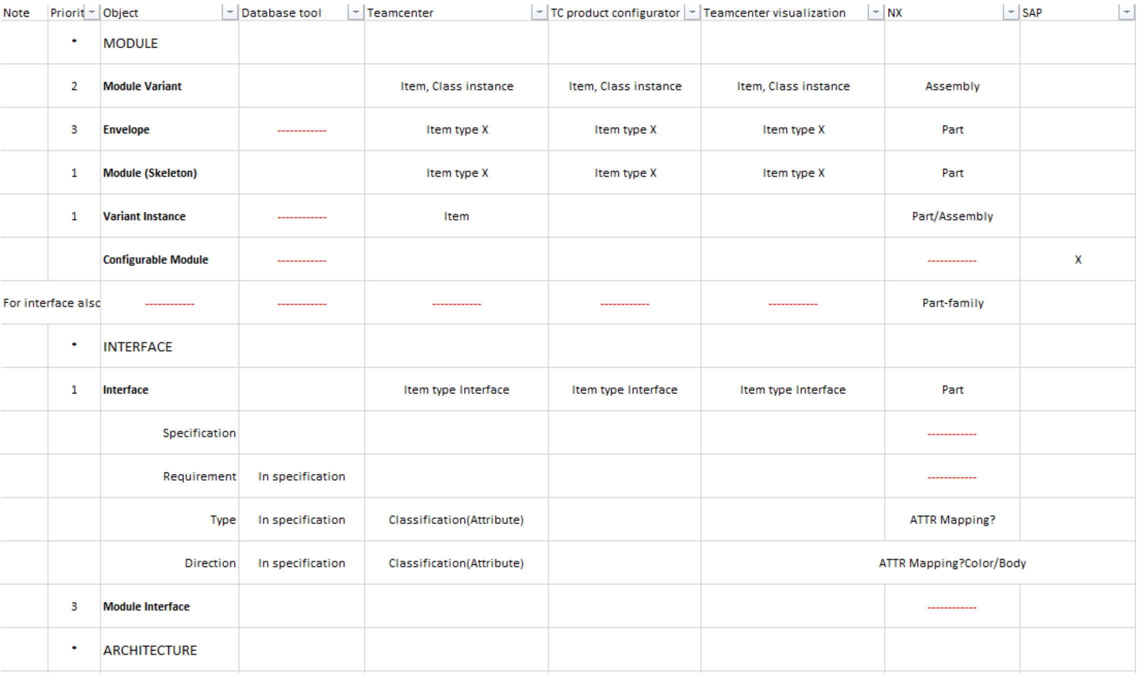
The case company uses combined sales configurator and product structure configurator that is currently integrated to the ERP. It has served the configuration needs satisfactorily even though it is laborious to use. The configuration work consists of some manual work that cause risks to the overall process. Scattered production and frequent product updates are another source of risks and the quality may decrease. One of the challenges is that the as-built structure is not agile for updates as it needs to be revised when changes occur. As-maintained product structure is intended to serve this requirement. Some of the documentation work has been outsourced which can lead to mistakes. Currently the configuration data stays in ERP which cause unnecessary work. In the future it is mandatory to attach the configuration information into the product individual.

The configuration work and knowledge about configurations are intended to be implemented in the architecture management tool in the case company. Some customer related information, such as prices are not entered into the architecture management tool. Product structure configurator will be integrated into PLM. In the future the cooperation need of configuration work will be emphasized between architecture management tool, PLM and sales tools. Especially the challenge will be in information transfer between PLM and customer related sales configurator information. The objective is to extend access into some parts of the sales configurator for customers also. It will give more sophisticated information for the customer about the configuration task. In the future the configuration work needs significantly more consideration due the modular product structures. The level of automation on data flow from sales configuration into product individual needs to increase to avoid human errors.

6.8 Modular object comparison between the IT systems

The third modeling exercise established the basis for the modular object comparison. The modeled entities according to the new modeling methodology concretize the new object types in NX. Simultaneously with the modeling exercise new questions and solution alternatives arose concerning the modular product data recognition. The architecture management tool for a modular product brings new definitions for a modular product. At the same time as the modeling exercises proceeded it turned out to be clear that there is a need for new kind of data objects in Teamcenter and NX. As the modular product is considered for the first time in the case company's IT systems there are no existing rules or guidelines for the modular product recognition. Therefore, the defining started from mapping different solution options and too strict solution rules were avoided at this point.

The preliminary suggestion for the management of a modular product in the IT systems is presented in Appendix D. Part of the object comparison starting point before discussions with different parties is illustrated in Figure 48.



Note	Priorit	Object	Database tool	Teamcenter	TC product configurator	Teamcenter visualization	NX	SAP
	•	MODULE						
	2	**Module Variant**		Item, Class instance	Item, Class instance	Item, Class instance	Assembly	
	3	**Envelope**	------------	Item type X	Item type X	Item type X	Part	
	1	**Module (Skeleton)**		Item type X	Item type X	Item type X	Part	
	1	**Variant Instance**	------------	Item			Part/Assembly	
		Configurable Module	------------				------------	X
For interface alsc		------------	------------	------------	------------	------------	Part-family	
	•	INTERFACE						
	1	**Interface**		Item type Interface	Item type Interface	Item type Interface	Part	
		Specification					------------	
		Requirement	In specification				------------	
		Type	In specification	Classification(Attribute)			ATTR Mapping?	
		Direction	In specification	Classification(Attribute)			ATTR Mapping?Color/Body	
	3	**Module Interface**					------------	
	•	ARCHITECTURE						

Figure 48. *Object comparison starting point between architecture management tool, Teamcenter and NX*

For the modular product object comparison, the architecture management tool, Teamcenter and NX were chosen to be on the focus. The objects were divided into three main categories: module, interface and an architecture. The comparison data was entered into Excel and for the objects corresponding definitions and objects were found if existed in the other systems. As can be seen in Figure 48 module, interface and architecture objects are listed in the rows and the corresponding object utilizing systems are marked as columns. If there is no counterpart for the object in an IT system, the node is marked with a red line. As this was just a preliminary hypothesis about object utilization in the IT systems before discussions with all parties some of the nodes stayed empty at this point.

This chapter introduces the case company and the case. The current design methodology and possible future methods are considered. The chapter presents findings how to manage a modular product in IT systems and how to proceed the future configuration work in the case company.

7. ANALYSIS

In this chapter there is an analysis about findings in literature review and in the case. The focus is on modeling methods, IT systems and product structures. Modeling methods and configuration methods are analyzed between findings in literature and the case. IT systems and product structures are considered more in the context of the case company.

7.1 Modular modeling

Management of a modular product data will bring on changes for modeling methods. Modeling methods guide strongly the daily design work. The maintenance of different module entities presented in the second exercise in Chapter 6.3.5 can become laborious. This is due to the number of different objects. When the modeling methodology is chosen the methodology will not remain unchanged, but it will evolve a lot instead. This is because the methods now are still quite new and there is a lot of potential to improve. One source of a concern is the maintenance of the modular design methodology. It can become complex due the amount of linked modeling entities as there have been issues with the wave links in the case company.

There is a lack of standardized methods for modular product modeling in literature and among software providers. One reason for that can be that the modeling method related issues are usually underestimated. In practice companies have variable solution methods for modular product modeling.

Modeling methods are product related in the context of modular products. If the product variation level is low, then the configurator will not affect the design work, until the configurator only chooses the options. When variations exist on many levels the configurator can have impacts on the design work. The configuration phase may include parameters that are connected to the design objects. There are many available tools to ease the design work for modular products. It is crucial for the case company to pick the right tools from the assortment.

Mechanical interfaces are only considered in this study due the limits of resources. There might arise new challenges for the design methodology when other types of interfaces will be exploited, and more complicated modules are created.

According to the definitions of interfaces in Chapter 5.2.4 the responsibility of standardized terminology is company specific. The language to recognize modularity in the IT systems need to become standardized so it will help the work with modular products. There is especially a need of standard terminology for modules and interfaces. Also, the change processes need to get standardized and documented in a standard way. The ownership and responsibility of a product, architecture, module and an interface need to be defined and documented in a standardized way to ensure avoidance of uncontrolled changes. The recognition of item needs to consider in a new way in the future. An individual design item can relate to several purchase items, for example an electrical motor can have one design but many different variants from suppliers. On the other hand, the same purchase items can relate to several different designs. For those reasons the definition of item needs consideration soon to minimize unnecessary manual work.

7.2 IT systems and product structures

Every company has an individual need for the set of IT systems. There are lot of changes in the case company's IT systems. Some of them are obsolete and the existing systems are inadequate for the future needs. The literature suggests dividing the configuration task for sales and product structure configurators. The case company is going to divide the configuration among product structure configurator, PLM and sales configurator. The division is mandatory for the case company as the modular products require it.

The scenario of the future set of IT systems described in Chapter 6.6 is only one possible solution. Due the changing environment and huge amount of involved parties it is impossible to consider the future exactly. There are multiple factors that can have impact to the future set of IT systems. The uncertainty can be seen divided into two main categories. Business related aspects have direct impact on the IT aspects. There are some examples below:

Business aspects:

- Supply chain needs
- Customer requirements
- Legislation requirements
- Changes in business strategies
- Executive managers
- Software providers
- Changes in products

IT aspects:

- IT system harmonization in the corporation
- Changes in software support
- Software developments
- Changes in number of needed licenses
- Software license prices
- Data migration issues

For the reasons described above the individual documents managed by systems were left outside of the consideration in the future IT system scenario. This causes risks to the future IT system draft as some of the aspects may have been overlooked or misplaced there.

As mentioned in Chapter 7.1 there is a close relation among modeling methods and configuration work especially in a case when configurator controls the design parameters. There is a need for experts for architecture management tool from the case company side. They supposed to gather knowledge how the new software should be applied and especially how it will be integrated to the other systems. The results of configurations need to get automatically from there to the PLM and sales software.

The product structures of the case company will go through enormous changes. Traditionally the case company had dedicated product models as a base of configuration work. The modular product will be structured from building blocks and there are no strict preliminary structures but configuration rules instead. The example of product data management in Chapter 6.4 describes only the principle of the product structure. In the future the module structure for conveyor will differ compared to the example. The final modular product structure will determine the possible solution methods in practice.

As mentioned in Chapter 6.7 there is need to extend the as-built structure and add an as-maintained structure additionally. As-maintained structure considers for example, the upgrades made for the product individual. There is a need to consider what kind of product structures the case company will maintain in the future.

This chapter analyzes the findings from literature and the case. It considers the value of the gained data. The possible sources of inaccuracy are presented. Considerations are mainly related to the modeling methods, the set of IT systems and needed product structure of the case company.

8. RESULTS

This chapter includes the main results of this study. The results include suggested modeling methods and considerations of future IT systems of the case company. The research questions that were presented in Chapter 2.2 are answered here.

8.1 Results

The preliminary feasibility study to support future modular modeling methods is described in Chapters 6.3.3-6.3.6. The purpose of the study was to find out a way to manage a modular product in the case company's IT systems and document it. As a result, the new modular designing method was applied and tested by company related models. These dummy modules presented in Chapter 6.3.6. The dummy modules are the first prototypes to adapt the new modeling methodology for the case company's product assortment. The next generation of dummy modules is under investigation.

Modular product assortment requires supportive modular modeling methodology to ensure the benefits of modular product family. Modular modeling methodology ensures the independence and interchangeability of the module variants over updates. This is achieved by standardization and documentation of modules and interfaces. Part families and libraries are efficient tools to store data about variants. The suggested architecture management tool related modeling method do not support them. Coordination systems need direction rules and all the models need to be fully constrained to support modular product modeling. For every module it is essential to visualize the interfaces and space reservations, color coding is suggested. This ensures that the designer always notice the crucial elements. Table 1 describes the main design requirements of modular objects.

Table 1. *Requirements for modular product design objects*

Design object	Requirement
Module	- Includes a standardized envelope and interfaces - Module library in PLM
Module Variant	- Includes a standardized envelope and interfaces - Has required product structures, for example eBOM and mBOM
Interface	- Has a direction and Male/Female representations - Visible and color coded in every design phase - Interface library in PLM
Envelope	- Visible and transparent in every design phase - DFMA considerations, for example assembling space reservations - Considers manufacturing and assembly variations
Architecture	- Design variant created without replacement of modules - Representations for module envelopes and interfaces - Global coordinate system rules - Fully constrained - Follows configuration rules

There are a lot of requirements for functionality and ease of use for the systems. These new requirements will have an impact for the modular design object management and object recognitions.

The current set of IT systems in the case company is in Appendix B and the consideration for the future IT systems is in Appendix C. The current set of IT systems is obsolete and does not serve modular product data management. The role of PLM system will be emphasized in the future as the configuration work will be implemented there instead of ERP. It is suggested to use a product structure configurator that creates the product variants from preliminary module assortment among the product scope of the thesis.

The principle of future module recognition in architecture management tool and Teamcenter is described in Appendix A. The architecture management tool manages the information about modular objects but not all the data of them. All modular product data will be stored in Teamcenter. The modular object terminology for now is in Appendix D.

8.2 Research questions

According to the literature review and research work for the case company the research questions presented in Chapter 2.2 are answered here. An emphasis of the answers is in the context of design according to the practical part of this study.

1. *What are the capabilities and restrictions of IT systems for modular modeling?*

There are many options and tools to model a modular product. The systems enable modeling for interfaces, space reservations and coordination system rules. The methods need to be simple and compatible with other systems. It is beneficial to use methods that visualize the key elements of a modular product. According to the feasibility study for presented modular modeling methods they are laborious compared to the traditional modeling methods. When some method is applied it easily excludes other methods from use and restricts the use of modeling tools.

2. *How is the product structure of a modular product in a PLM system stored?*

There is a need for as-maintained structure besides as-built structure to serve lifecycle related product data. The generic product structure needs to be separated from the overloaded BOM that consists all the module variants. Product families and libraries for modular product objects are useful for controlling variability and access rights. Utilization of visual product structures is suggested.

3. *How is the maintenance of product data performed?*

In the case company the product data of modular products will be managed in the architecture management tool. Modules, interfaces, configuration rules and the needed specifications are maintained in the architecture management tool. PLM system, ERP, modeling tools and tools for sales are supportive systems and they are storing and exploiting the created data. PLM system is responsible of the updated design data. After the modularization is done there needs to be continuous work to develop modules according the changing customer requirements. The customer requirements are also managed in the architecture management tool.

4. *How is data flow from sales configurator to product individual improved?*

The sales configurator and product structure configurator need to be separated to ease the data management and provide appropriate information for different parties. At the same time the integration between systems need to be automated to avoid manual work and human errors. In the future it is mandatory to add the information about the configuration work to the product individual due to the modular product assortment.

This chapter presents the results of the study. The identified modeling methodology requirements for a modular product and proposed solutions answer to the first research question. According the findings from literature and discussions among the case new types of product structures are suggested to support efficiently service requirements and perceive the structure of a modular product, for example as-maintained structure and visual product structures. These aspects contribute the second and third research questions. The fourth research question is answered mainly by the findings from discussions with the experts of the case company.

9. DISCUSSION

The literature review was divided into two main categories: PLM and a modular product. The considerations related to the modular product is extensive. Some of the specific topics could have been observed from different perspectives but the literature review is adequate for the research. The literature review enabled the gathering of the knowledge and supported the case study.

The availability of practical studies and best practices from industry that are similar with the case company's situation was low. The lack of these references sourced challenges for the practical part. Discussions with a company that already uses modular design methodology were arranged but due to the differences in product assortment and configuration methods it was not seen beneficial to continue cooperation at this phase.

It took a lot of time to adapt the new modeling methodology and it turned out to be laborious. The efficiency and suitability of the new modeling methods is difficult to measure for a reason that they are not implemented into use yet. The understanding of the methodology is mandatory and after this research the ability to improve the methodology requires less effort for the case company. The methodology that is used in the exercises is easy to adapt for the other case company's products. The case company needs to continue discussions about the modeling methodology internally and with the software providers to find improvements for it. At this point it needs to put effort on methodology evolvements as the case company is in early phase with the modular modeling methodology. Simplifications and compatibility with other design tools are the most important required improvements for the methodology. Consideration of visual product structure models is suggested for the case company.

The study will have impact how the future products will be recognized in the IT systems and especially how the modeling methods for them will be utilized. The product configuration work has a lot of impacts on design methodology and vice versa. The architecture management tool focuses on modularization and configuration knowledge. It is essential to understand its impacts on design work, configuration work and product structures. The utilization of different product structures needs considerations in the case company. In the future for example the benefits of eBOM, mBOM, as-built, as-maintained structures can be useful for the modular product assortment.

According to the interviews there is a need to change the corporate culture to enable modular product recognition. It means changes in practices and common language related to the modular products. The success in corporate culture change is the most important single factor for the case company. In the future the challenge will be identification of the methods that are beneficial to adapt to the case company way of working.

The architecture management tool will have the main impact for product data management in the case company. The delay on implementation of architecture management tool for the case company was the major challenge for this study. Information and provided material about the methods and architecture management tool were limited. The author got to access the system in a late phase, so the dummy modules were not entered there. Some of the provided documents were obsolete. Due to the lack of modular products in the case company the dummy modules needed to use in this study.

Despite the challenges the study revealed the gaps between current and future modeling methodologies. The study validated the modeling methodology in the context of case company's products. The study describes the needed changes for the IT system structure to support modular product data management and configuration. The detailed information about collaboration of IT systems succeed only partly due to the limited access and information about the architecture management tool. Also, documentation principles did not reach the aimed level of details. As a conclusion the study was a success for the case company as it gained information about modular modeling method requirements and is ready to continue improvements for them by dummy modules. The research questions were answered and the knowledge about modular product data management was increased.

Company related modeling methods differ compared to the examples of this study, but the basic methods are general. The leading principles for interface and space reservation recognition are not software depended. It is obvious that other companies go through similar challenges when applying modular modeling methodology. Therefore, in the author's opinion, the level of detail is suitable in this study.

Most of the modeling tools exploited in this study are not new. The novelty of this study is how to implement modular modeling methodologies in practice. There are no public articles about detailed modular product modeling methods. It can be assumed that instructions for modular product modeling exists in industry, but they are core competencies of the companies. There are several theories for modular product creation and Brownfield Process is relatively new. However, the theories do not support modeling methodologies.

The design of modular products is in a very early phase in the case company. It is crucial to adapt the best available methods at this point. The efficient modeling methods will bring significant cost savings for the engineering work. The modeling methods are relatively new, so it is mandatory to follow the method developments.

10. CONCLUSION

The purpose of the study was to clear up the methods for modular product recognition and management in a PLM system. The principles for a modular product management were carried out by findings from literature. The solutions in practice were created by coordination with the case company and the PLM related software providers. The author added opinions to the thesis. Specific IT system related possibilities and restrictions were considered in the context of the case company.

The research was carried out by determination of the problem and objectives. The main objectives were to achieve a suitable modular product modeling methodology and a supportive set of IT systems for that. The research strategy, methods and the research questions were formed to serve the objectives.

The literature review helped the author to understand the main principles and the characteristics of a modular product and its product structure. The findings from literature pointed out the requirements for IT systems in the context of a modular product. Also, suggestions for modular product data management were gained to lead the case study.

The modular design methodology was recognized and discussed to improve the case company's readiness to adapt it. The modular design methodology was not completed due the early phase of the modularization activities. The intention of the methodology determination was to enhance the case company's readiness to improve the methods to serve its purposes. The current set of IT systems were documented and the future vision for it was created. The focus was regarded how the systems will manage the modular product data and configuration work. Documentation leaded the author and improved communication about the study among the involved parties. The thesis also taught project work skills in the international team.

Interfaces and space reservations got the focus on modular modeling and they are made visible in every design phase. By that the benefits of modularization work are implemented and maintained in a corporation with several design engineers. In addition, the specifications for the modular design objects are required with need for a process for changing them to ensure the independence and interchangeability of the modules.

As the modularization is a way to answer the customer requirements and support the business strategy it is mandatory to document all the phases. When there come changes in those areas it is easier to update the modular product system. Modularization is never completed and there will be improvements in IT systems under this topic, so the company needs to continue the work to gain and maintain the market advantages.

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APPENDIX A: A MODULE RECOGNITION IN ARCHITECTURE MANAGEMENT TOOL AND IN TEAMCENTER

Unfortunately, the attachment contains confidential material so it cannot be presented in the public version of this thesis.

APPENDIX B: IT SYSTEMS FOR DATA MANAGEMENT, CURRENT STATE

Unfortunately, the attachment contains confidential material so it cannot be presented in the public version of this thesis.

APPENDIX C: IT SYSTEMS FOR DATA MANAGEMENT, PLANNED STATE

Unfortunately, the attachment contains confidential material so it cannot be presented in the public version of this thesis.

APPENDIX D: MODULAR OBJECT COMPARISON IN IT SYSTEMS

Unfortunately, the attachment contains confidential material so it cannot be presented in the public version of this thesis.