Product Structure and Information as a Common Model; A manufacturing company case study

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Summary

The ever-increasing customer demand for customized products is putting manufacturing companies under pressure as new products and product features must be introduced rapidly to the market. Product information and configuration are key elements for successfully handing the developing product portfolio and satisfying customer demands.

The need for product information varies between organizational functions and the purpose of this thesis has been to find out what the effects are, if the product information is not handled in a common way. This thesis has defined three research questions related to product information which have provided the theoretical framework. The study has been conducted in a case company in form of qualitative interview sessions providing a current state analysis. The target is to answer the research questions with the help of the theory and a current state analysis.

The study lists several effects caused by the lack of product information and product structure e.g. unwanted increase in product variations. The study concludes that product information is a subject of segmentation (data silos) in organizational functions. This results in interpretation of information as data from one silo must be matched with data in another silo.

The combination of the current state analysis and the theory provides a baseline for handling product information supporting a common structure applicable for all organizational functions. An example of a common product structure supporting the varying need of information is presented in the end of this thesis.

Language: English Key words: Product- information, -structure and- configuration, PLM and product portfolio management

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EXAMENSARBETE

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Titel: Produktstruktur och information som gemensam modell; En fallstudie i ett tillverkningsföretag

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Abstrakt

Kundernas ständigt ökande krav på skräddarsydda produkter ökar pressen på företag med egen tillverkning på grund av at nya produkter och nya produktegenskaper snabbt måste lanseras på marknaden för att bibehålla marknadspositionen. Information om produkten och produktens konfigurabilitet är centrala delar för en successiv hantering av en växande produkt portfölj samt att tillgodose kundens önskemål.

Behovet av information relaterat till produkten varierar mellan olika organisatoriska funktioner. Syftet med detta slutarbete är identifiera konsekvenser som uppstår om produktinfromation inte hanteras enligt en gemensam modell. Detta slutarbete centraliseras runt tre forskningsfrågor som direkt är relaterade till produktinformation. Dessa forskningsfrågor har satt gunden till den teoretiska ramen. Slutarbetet har utförts i ett företag i form av en studie bestående av kvalitativa intervjuver vilket har gett en insikt i den nuvarande situationen i företaget. Målet är att svara på forskningsfrågor med hjälp av den teoretiska ramen samt insikten i den nuvarande situationen.

Studien listar flera konsekvenser som orsakas av en bristande tillgång till produkt- information och -struktur t.ex. en oönskad utökning av produkternas varians. Som en slutsats för denna studie kan konstateras att produktinformation är subjekt för segementering där datan ofta definieras i datasilon. Detta fenomen resulterar tolkning av information p.g.a att data från ett segment måste likställas data från ett annat.

En kombination av den nuvarande situationen och den teoretiska ramen ger en god grund för en gemensam modell för att hantera produktinformation på så vis att den stöder tillgänglighet av data för alla organisatoriska funktioner. Ett exempel på en gemensam modell är presenterad i slutet av detta arbete.

Språk: Engelska Nyckelord: Produkt- information, -struktur och -konfiguration, PLM och produkt portfölj

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LIST OF ABBREVIATIONS

ETO – Engineer to order

CTO – Configure to order

MTS – Make to stock

BOM – Bill of material

ATO – Assemble to order

EBOM – Engineering Bill of Material

PLM – Product Lifecycle Management

PDM – Product Data Management

R&D – Research and Development

P&ID – Piping and Instrumentation Diagram

1. Introduction

Customers' demands on tailored products and solutions or variations of existing products and solutions in today's industry are putting pressure on companies' development of their product portfolios. If companies want to maintain their place in the market there is a high need to have a functional product portfolio management process in place where the products are effectively managed to cope with the ever-increasing demand of the customers (Tolonen, et al., 2015).

Customer demands on customization or tailored solutions often results in an explosion of the product portfolio to cope with variation of products. Companies that operate in business areas where the variance of the solutions are very high or where the solutions are considered unique often tend to operate according to a business model called engineer-to-order (ETO). In an ETO business model there is usually no existing product portfolio that can be used to combine products into a given solution. Instead the intention is to do engineering activities to get an understanding how the solution can be realized. When it comes to sales of solutions done in an ETO manner, there are often difficulties from the company's sales representatives to get a good grip of what can be sold. Hence it is not given that sales, product development and production have a common understanding on how to manage a complex product portfolio (Kropsu-Vehkapera, et al., 2011). According to (Kropsu-Vehkapera, et al., 2011) this will potentially lead to cases where the customer is offered products or solutions that are hard to realize.

Configure-to-order (CTO) is an alternative approach where companies try to cope with variations and tailored solutions by the introduction of a product structure and a product portfolio that can be configured in different ways to satisfy the need of the customer without doing up-front engineering work in the sales phase.

1.1 Background

In an ETO business model there is usually no or a very limited product portfolio available that can be used to realize a product or solution that can satisfy a customer's needs. This gives rise to a series of problems especially in relation to the product life cycle management and the product portfolio life cycle management. As there is a need to support the customer throughout the lifecycle of the product or solution, the need for storing data becomes increasingly higher and trickier in an ETO business model. Therefore, there is a desire to move towards a CTO business model where there is an underlying product portfolio that can be used upfront to configure product or solutions already in the sales phase without doing engineering activities.

1.2 Research objectives

Given the above, this master thesis will focus on investigating and analysing the possible implications associated with a vaguely defined product portfolio and a low amount of product configuration constraints and rules.

This thesis aims to clarify the possible complications that can emerge from poor product definitions and structures by answering the following research questions.

1. How is sales/offering impacted by product- definition and structure?
2. How is product/solution configurability related to product definition?
3. How is project execution affected by product- definition and structure from sales?

Each research question will be answered by reviewing current literature and research in relation to the subject as well as comparing challenges experienced in product lines with a variety of experience and maturity in terms of product definition, product portfolio and product configurability.

1.3 Research process and methods

The research process was of the qualitative manner and started with the definition of research areas and research questions that were to be answered by this master thesis. In order to answer these, a qualitative study of different cases was done in selected business areas representing a variety of maturity levels in the terms of product- configurability and definition. The qualitative study included interviews with carefully selected stakeholders representing different functions in the same product line to capture the different views on products and product configurability. The qualitative study also included an in-depth analysis of the existing product definition and product configurations in the selected product lines. The research process is illustrated in the following figure.

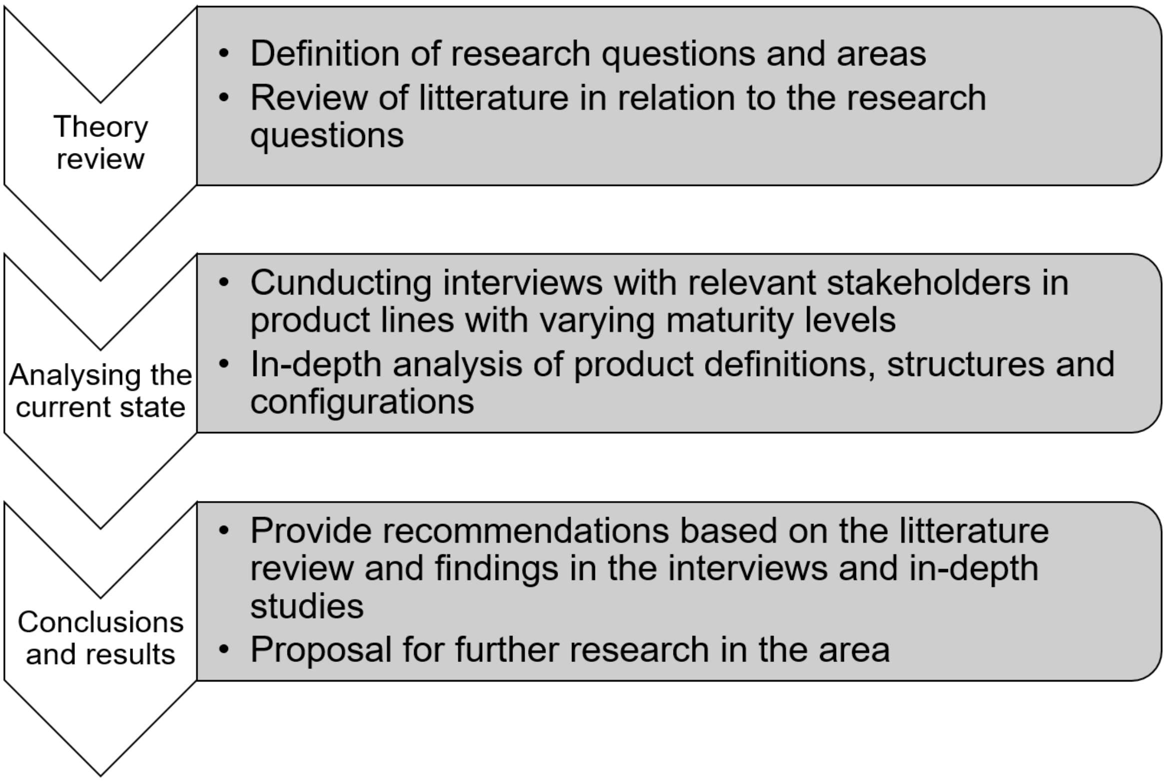

Figure 1 Research process

2. Theory review

In this chapter I will review the current literature and research about product definitions, product structures, product configurability and product portfolios. The literature review will be presented in a structured way covering all the previously mentioned aspects.

2.1 Product definition

With the ever-increasing demand from customers, companies are forced to rapidly introduce new products or product features to the market. This often results in a rapid growth of the product portfolio or a rapid expansion of available product variants (Tolonen, et al., 2014). According to Tolonen, et al. (2014) the explosion of the product portfolio and the increase of different product versions are adding another element of complexity in terms of product portfolio management and product portfolio data management.

In companies that are providing very complex products or even solutions, consisting of any given combination of products, the product portfolio management and product data management becomes increasingly hard since there seems to be very often a mix in understanding of what the product really is in the context of solutions. The requirements of the product are usually different during stages of its lifecycle. For example, sales and marketing organization might treat the product or product portfolio in one way using certain processes and applications when e.g. services might treat the product in another way using other processes and other applications (Stark, 2011). In bigger companies that market themselves as being total solution providers, the understanding often seems to lean towards the complete solution being the product even though de facto it is a combination or configuration of different products fullfilling the customer needs. This is a phenomena that Stark (2011) refers to as "mixing part and product". According to Stark (2011), a product can be seen as a part in one context while it is seen as a product in another. One example of this would be when a customer purchases a mobile phone. In the eyes of the customer the box containing a phone, a charger and a headset is the product. This same perspective can be applied by the seller, making the charger and the headset a part of the phone product. But if a customer purchases only a charger, then the seller sees the charger as an individual sellable product instead of as a part.

Traditionally products are seen as tangible physical things that are manufcatured. Kropsu-Vehkaperä (2012) takes the definition of a product further and defines a product as hardware, software or services. The very similar categorization of products is also recognized in other Product Lifecycle

Management (PLM) litterature such as Stark (2011), (Tolonen, 2016) and (Sääksvuori & Immonen, 2002). Kropsu-Vehkaperä (2012) also states that a product can consist of any given combination of these three categories wich is also supported by (Tolonen, 2016).

2.1.1 Product variants and versions

Product versions and product variants are often confused and sometimes new product versions are even launched and marketed as new products. To avoid further confusion between the two similar words (but very different meaning), the terminology needs to be sorted out.

A product variant can be seen as a variation of a given product that satisfies a set of requirements (Kropsu-Vehkapera, et al., 2011). An example of a product variant could be an internal combustion engine with a given output power. Kropsu-Vehkapera, et al. (2011) says that a number of product variants exist in the product portofolio in parallel for a configurable product and the product variants are extending the portfolio. This means that a manufacturer of internal combustion engines can have a portfolio of different engine variants producing different output powers which are all available in parallel in an active sales portfolio.

A product version is different from a product variant since they do not exist in parallel with other versions in a product portfolio. A product version is usually an upgrade of an exsiting product to achieve cost-down, better performance or quality (Kropsu-Vehkapera, et al., 2011). An example of a product version could be an internal combustion engine that meets the same set of requirements as its predecessor but it utilizes different internal components making it cheaper to manufacture. In other words, a product version replaces it predesessor making only one version available in an active sales portfolio.

2.1.2 Product structure

Product structure can be seen as a concept used hierarchically to represent product data and information in a structured way. In fact, Sääksvuori & Immonen, (2002) have defined product structure as follows: "*Product structure is a concept model that describes the information of the product and how it relates to other information. Information and its relations are described formally. In practice, the product structure describes hierachically, using items, how the product can be generated.*" In a company that is producing and delivering very complex products or solutions the product structure is of very important essence. Different functions in an organization have a need for the product information in their own context. According to Lea, et al. (2010) the different functions in a company have a need for different levels of product information. For example, a salesman might only be interrested in the sales item level data of a product while engineering functions might be interested in the component or bill of materials aspects of the product information. Lea, et al. (2010) says that different functions are only interested in a level of information that is applicable to their own function. Sales are usually only interrested in the higher levels being e.g. the products or the so called sales items, while e.g. purchasing is only interrested in the lowest level of information wich is the components or materials that needs to be purchased in order to realize the products or sales items. The product structure concept is illustrated in figure 2 below.

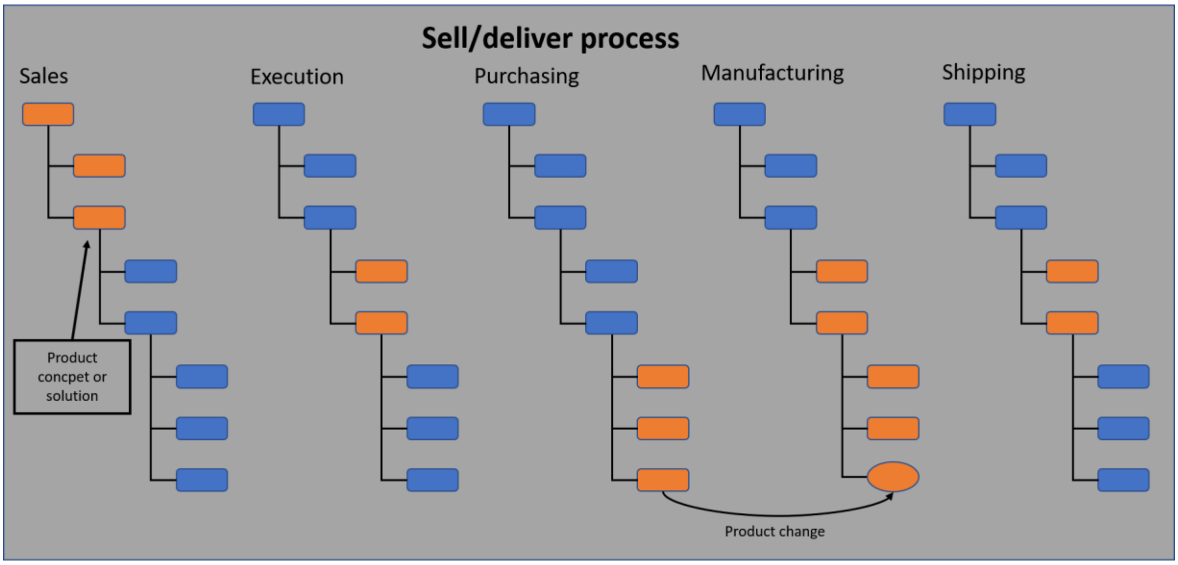

Figure 2 Modified picture from Tolonen (2008) via Lea et al., 2010

Different functions in a company see the product information in different forms which means that the product information and product structure is actually changing throughout the functions with complex products (Lea, et al., 2010).

In a business model where complex solutions are offered, the product structure and product information are often subject to change during its lifecycle. It is therefore of utmost importance that the product structure supports the changes that might occur in the lifecycle. (Lea, et al., 2010)

According to Sääksvuori & Immonen (2002), a product structure is the enabler of some of the very basic functionalities in a PLM system. Product structures are often built by using an obejct oriented approach where an object is a specific data element that is descrbing parts of the product such as an assembly, a system or a component. All the objects in the strucutre have dependencies to other objects in the structure. These dependencies can be functional dependencies as well as hierarchical dependencies. The linking or structuring of the describing objects (both functional and hierarchical) form the product structure where each and every object describes certain aspects of the product in a strucural way.

Sääksvuori & Immonen (2002), says that a product structure can usually be divided into 5 different levels of abstraction. The levels are presented below in the example of a cellular phone as Sääksvuori & Immonen (2002) have presented it.

1. The product level. The highest level is the product level and there is only one object describing this level. The physical representation of this level would be the complete sales package.
2. Component level 2. This level is dividing the components that are to be packed (or shipped) to the customer. The physical representation of this level could be, for example, a phone, a charger, a headset and a manual.
3. Component level 3. This level divides the product into parts needed to be manufactured. The physical representation of this level could be e.g. the circuit board assembly, the screen and the outer covers that are going to be assembled into a complete phone.
4. Component level 4 is usually the sub level of the assembly level it belongs to which can be e.g. the circuit board and the software needed for the cuircuit board assembly in the previous point.
5. The lowest level is the part or element level that describes individual parts of the sub assembly used in an assembly. Such as an individual electrical part used on the main circuit board for the phone.

Sääksvuori & Immonen (2002) says that the top level is the product and that the physical representation of this could be the sales package. In other words, the product level is the combination of all the sales items that will satisfy the customers needs.

Comparing the segmentation of the product levels in a structure with the model that Tolonen (2016) presents when using the structure in the context of a product portfolio, one can see that there is a difference in the definition of what the top level actually is. Tolonen (2016) has stated that the top level is actually the solution which would consist of a product configuration. By a product configuration he means the combination of product variants that satisfies the customers needs.

Even though Sääksvuuri & Immonen (2002) and Tolonen (2016) sees the top level of a product structure as different it is reasonable to conclude that they are speaking of the same thing but having different viewpoints on the definition. A customer might be of the impression that he is bying a single product (e.g. the complete phone package) which is the top level as Sääksvuori & Immonen (2002) describes, while the company manufacturing the the product actually delivers a number of products (or sales items) fulfilling the customers needs being e.g. a phone, a charger and a headset.

Given the above, one can conclude that the defintion of a product is a strategic decision by the company. For example, as earlier mentioned a product portfolio can be defined in such a way that a decision has been made that a mobile phone is only sold in combination with a headset and charger making it into a single entity while likewise it could be possible to decide that there is another (optional) product, such as a cloud storage solution, that can be bought in combination with the mobile phone. These other optional products are not to be confused with optional items as Stark (2011) describes where he instead means that one product has optional features such as cruise control option for a car.

2.1.3 Products and product structures in sales

According to Kropsu-Vehkapera, et al. (2011) it can be difficult to define what the products or the sales items are in a sales phase. This is especially true for companies having a wide range of products in their product portfolio. A wide product portfolio often results in a vast range (often several thousands) of different product configurations and different product variants. Sales, product development and production do not necessarily share the same understanding of the resulting compleixity (Kropsu-Vehkapera, et al., 2011).

Kropsu-Vehkapera, et al. (2011) states that one of the key challenges in product configuration management is something referred to as "*Fuzzy offering*". Fuzzy offering derives from a poorly defined product definition and a poorly defined product structure. Due the the varying needs and requriements from different customers, the product and product variant configurations can be vast. This leads to a scenario where sales is incapable of managing the data in a controlled way resulting in the possible risk of offering incomplete or incompatible solutions to a customer (Kropsu-Vehkapera, et al., 2011).

In companies where time between contract signing and project execution are long, the product definition and the information of its context becomes increasingly important for all stakeholders. If the product definitions and product structures are not adequately defined, sales will be incapable of making offers with accurate cost calcuations as well as being incapable of preparing offers that are optimal for the business (Kropsu-Vehkapera, et al., 2011).

Kropsu-Vehkapera, et al. (2011) interviewed several case companies about product configurations and one of the interviewees, in one of the case companies, gave a statement on total solution offering which was: "*The first thing is to define offered products and understand the composition of a product, and after that it is time to think variants and configurations*". Kropsu-Vehkapera, et al. (2011) states that it is an exception that companies are having a common understanding on the product definition and product structure throughout the organization. Kropsu-Vehkapera, et al. (2011) goes on to say that the most problematic cases are where one product is seen to be part of another e.g. product A is part of product B. These can be seen as nested product cases where a combination of products define another product (product C). The problem in cases like this is to identifie what the actual sales items are.

Usually sales is translating the customer requirements into a product or a number of products that satisfy all the requirements. Considering the interviwee response in Kropsu-Vehkapera, et al. (2011) it is clear that sales is not always capable of easily connecting the requirements from customers to given products. This is very typical in engnieer to order (ETO) business models where the requirements are the basis for building a uniqe solution from a portfolio of components instead of a portfolio of products. The sellable items or products that need to be identified are illustrated in figure 3 below.

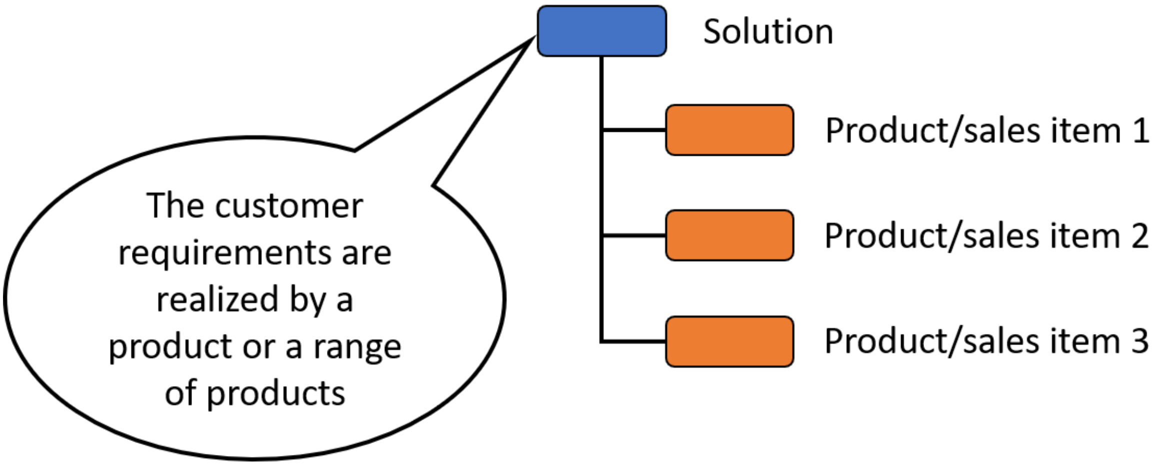

Figure 3 Sellable items or products that needs to be defined by sales

2.1.4 Products and product structures in project execution

As previously mentioned, there is often a misalignment on the understanding of a product definition. In bigger companies having specific engineering organizations for given product lines, the mixed understanding of product definition becomes an increasing problem. In the eyes of the customer, the product is what they purchase while in the eyes of engineering functions, the product is usually the complete assembly that is built from components in their component portfolio to realize a set of customer requirements within their own area of responsibility.

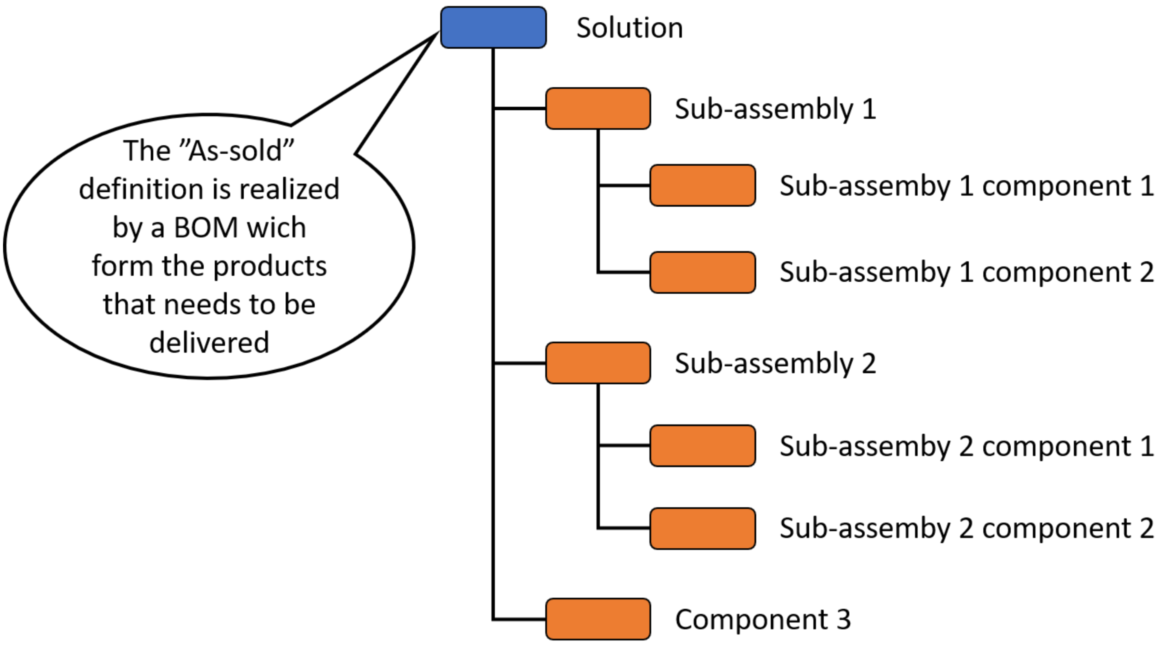

Figure 4 The assemblies and components that needs to be managed by engineering to meet customer requirements

The structure of assemblies and components is usually named the *Bill of Material* (BOM). In figure 4 above, the BOM is illustrated as often seen by engineering functions.

The BOM is a fundamental building block af a product which can be used for planning, both in the long term and in the short terms. The BOM is traditionally seen as a document or a structure that is used solely for production when it is in fact a strategic document that determines the product configuration and the product cost (Wacker & Miller, 2000).

According to Wacker & Miller (2000), the BOM is most commonly used to buy or produce all components and/or sub-assemblies required to realize a product or a range of products in such a way that when a customer order is received, the customer specification can be met exactly by the components and assemblies in the BOM. In order for this to work, Wacker & Miller (2000) assumes that the manufacturing function has bought or made all components that are part of the BOM.

According to Kropsu-Vehkapera, et al. (2011), a poorly defined scope of supply or a vaguely defined list of sales items will prove hard to manage in later phases by different stakeholders. Stakeholders in later phases of customer projects will have issues in handling the scope of supply if the list of sales items are not defined well enough. A BOM is the artificial grouping of items or events used to facilitate scheduling and/or material planning (Wacker & Miller, 2000). If the product information is not defined, customer deliveries will be challenging to handle since the information specified from sales cannot be associated with a BOM (Kropsu-Vehkapera, et al., 2011).

There are also other stakeholders further down the project timeline that will be affected by a list of sales items that is not adequately defined. According to Kropsu-Vehkapera, et al. (2011), the spare part information for after sales becomes tricky to handle since it cannot be associated with the sales item definition.

2.2 Product portfolio

Depending on what type of business model e.g. make to stock (MTS), configure to order (CTO) or engineer to order (ETO), a company has chosen to operate according to, a product portfolio can consist of different kinds of product types. Schomburg 1980 (via Pulkkinen, 2007) has categoroized product types in a product portfolio into 4 different types.

1. Standard products
2. Standard products with variants defined by the company
3. Standard products with variants defined by the customer, and
4. One-of-a-kind product.

The standard products are products often mass produced to stock with no variation e.g. a radio which is the case when speaking of operation in a MTS business model. Products that have variants defined by the company can also be produced to stock depending on the complexity of the product or they can be so-called assembled to order (ATO) products which are consisting of pre-defined modules that form the end product. An example of this would be a car that allows for certain customization defined by the company such as different kinds of interior and different sizes of rims etc. Product variants defined by the customer usually need to be configured and might involve some aspects of design depending on the requirements of the product. An example of such a product would be a house where the house is built in predefined house modules but the customer requirements are specifying a certain material for the façade. The one-of-a-kind product type is designed and manufactured according to an ETO business model where customer-oriented engineering is required at many stages in an order-delivery process. An example of such a product would be power plant. (Pulkkinen, 2007)

A one-of-a-kind product such as a power plant, can consist of different product categorizations. For example, a power plant can consist of standard products, company defined variants and customer defined variants. Similarly, a product variant defined by a customer can consist of standard products and product variants defined by the company, but it cannot incorporate one-of-a-kind products. This makes the categorization of the products unidirectional. (Pulkkinen, 2007)

In spite of the technical categorization of the different product types presented by Schomburg, 1980 (via Pulkkinen 2007) it is certain that the design aspect is very different in each case. For example, standard products allow zero variation on the products and there is no design of the product. The customer involvement is purely a selection of products. If variants are defined by the company, the design of the products starts to play a role as the customer involvement incorporates configuration of the products. For variants defined by the customer the latter in combination with design activities are required where the design might prove more challenging. For one-of-a-kind products, customer-oriented engineering is usually required in many stages in a order-deliver process. (Pulkkinen, 2007)

Tolonen (2016) describes a product portfolio as being twofold, it has a vertical and a horizontal aspect. Tolonen (2016) describes the horizontal portfolio as a portfolio of products in different phases of the product lifecycle. In other words, it is the portfolio of products in the new product development phase, the products in the maintain portfolio, the products in the warranty portfolio and the products in the archive portfolio. Due to the limitations of this master's thesis, the horizontal aspect of the product product portfolio will not be discussed in further detail.

The second aspect of the product portfolio that Tolonen (2016) presents is the vertical product portfolio. The vertical product portfolio is a way to hierarchically describe the product structure as they are exposed to the customer and how they are handled internally. The vertical product portfolio also describes how information is hierarchically related to other pieces of information (Sääksvuori & Immonen, 2002). The vertical product structure itself is also twofold. Tolonen (2016) divides the product portfolio into a commercial defintion of the product portfolio and a technical definition of the product portfolio.

The definition of the product portfolio should be done in a top-down manner, starting with the solution, going down to product family, continuing on to product configuration and then ending on the sellable items (or individual products) level which defines the commercial aspect of the product portfolio. The sellable items might need further internal structure which reflects the assembly of the sellable items (Tolonen 2016). Therefore, the technical product portfolio definition is made up of of different components being part of assemblies or sub-assemblies, in the case of hardware sales items, or processes and sub-processes in the case of service sales items (Tolonen, 2016).

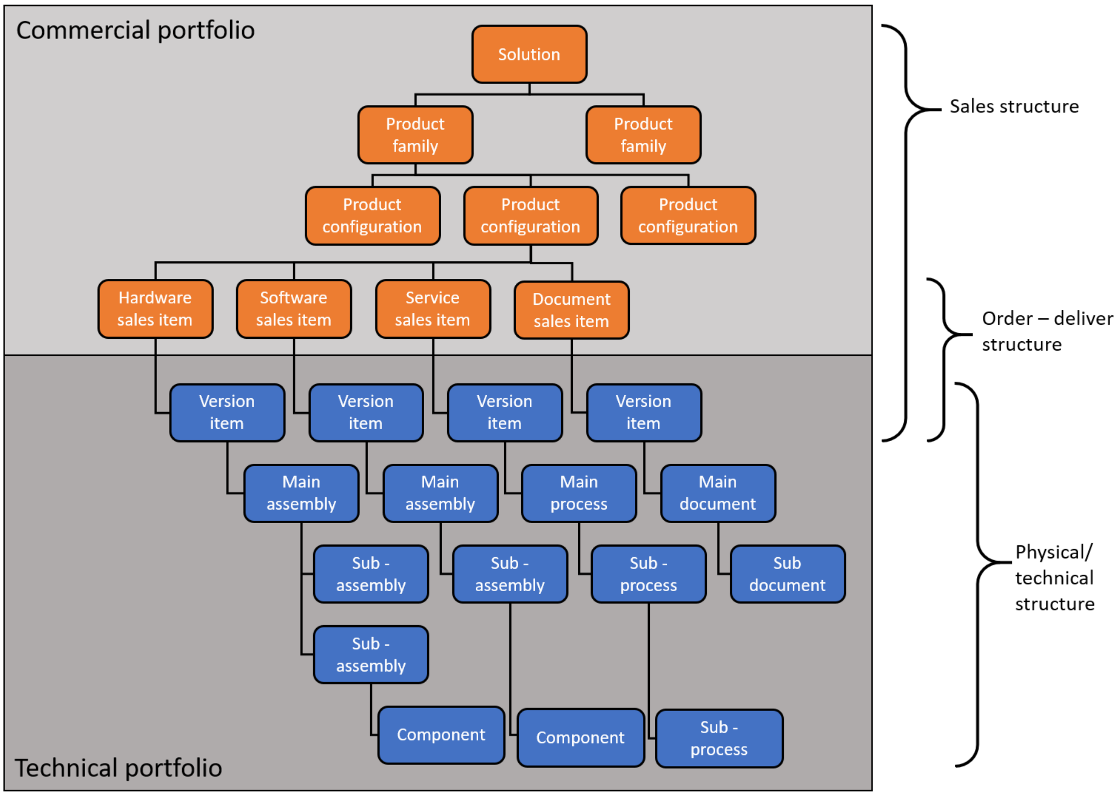

Figure 5 Modified vertical product portfolio from Tolonen (2016)

2.2.1 Product portfolio – different aspects

There is often a need to have different information of a product available in different organizational functions. For example, the sales department is in need of commercially related information while the engineering departments would have a need for information related to the technical aspects such as assemblies, components and parts.

If the product portfolio is not defined in such a way that this retrieval of information is supported, organizational functions might be in need of finding solutions that satisfies the retrieval of information to a desired level. This can often result in scenarios where the product information is stored in different systems instead of being centrally stored and maintained in a common PLM system.

This way of working is often referred to as the siloed way of working where each organizational function e.g. the sales department sets up a solution satisfying their individual need. (Mello, 2002)

David Sherbourne said during the PI PLMx event in London that a solution like the above mentioned is causing segregated systems and the information stored and generated in each organizational function is often not in sync and hence it makes the flow of information prone to error. Sherbourne even said "*todays companies are littered with databases set up to answer very narrow questions*". (Sherbourne, 2019)

In the following two chapters I will go into more detail about the information of a product needed by different organization functions that are covered by this thesis, namely the commercial part needed by a sales department and the technical part needed by project execution organizations.

2.2.2 Product portfolio – the commercial aspect

According to Kropsu-Vehkaperä (2012) it is important that sales functions in a company are capable of identifying the products or the sellable items before any detailed configuration can be made. The Product configuration can be done on two levels (Sääksvuori & Immonen, 2002) which are often referred to as sales and engineering configuration or front- and back-office configuration (Pulkkinen, 2007). For a selling function in a company it is important that a product configuration can be made at a higher level where all the customer requirements can be captured and translated into a product or a product range. For an engineering function on the other hand it is more important to configure products (or sellable items) individually to produce the BOM for manufacturing purposes.

Tolenen (2016) has crystallised his definition of the commercial product portfolio by making a very simple comparison to a meal configuration from a fast food restaurant. The solution is consisting of what the customer requires which is realized by sellable items from a product family satisfying the customers needs. Tolonen (2016) states that the product configuration , in a selling phase, is made up of one to many sellable items (one to many products) where each and every sellable item (or product) satisfies one or more customer requirements. Phrased differently, one can say that sales are making product configurations by translating customer needs into sellable items (or products). This forms the scope of supply or the list of sales items.

Here it needs to be noted that the sellable items (or products) defined in the scope of supply or list of sales items are going down to the product variant level. Tolonen (2016) has presented his example where a pizza, a soft drink, a sallad and home delivery are the products in the scope of supply. The pizza, for example, is the product that is being delivered, but a customer can have requirements making the pizza into a product variant such as a quattro staggioni. Stark (2011) describes the product variant as a variation of a basic product (different toppings in this case).

2.2.3 Product portfolio – the technical aspect

As previously mentioned, there are two aspects of a product portfolio, namely the commercial and the technical aspect (Tolonen, et al., 2015), (Sääksvuori & Immonen, 2002). The technical aspect is, apart from the commercial aspect, focusing on defining the design (the assemblies and the BOM's) of different products that are part of the product portflio.

Sääksvuori & Immonen (2002) have exaplained the technical portfolio as being the part of the product architecture that links the physical structure of the product to its functionality which is the relevant information needed on the commercial level.

The previous chapter exaplined the commercial product portfolio of sellable items for a fast food restaurant where a simple meal configuration was done. That commercial product portfolio has a tight link to the technical product portfolio since the technical portfolio is the structure of physical parts to the commercial definition. As an example, a product variant (a quattro stagioni) can be technically realized by assemblies and parts (or more presisely ingredients in this case) where one assembly could be the dough having the parts (ingredients) water, flour and yeast. Other parts (ingredients) could be the toppings. The dough, being one assembly, is part of a technical product portfolio and this assembly needs to be linked to it characteristics and funtionality (the commercial definition).

The technical product portoflio aspect can be seen as the lowest three levels of the five level deep product structure that Sääksvuori & Immonen (2002) has presented.

The components and parts available in a technical portfolio can consist of fixed pre-designed modules or more generic design structures that allow for variations such as having opitonal parts included in the design or having structures allowing for alterinatives. The later is more efficient to use in combination with a configurable product as the fixed pre-designed modules can easily rise to thousands or even millions of combinations and a change on a commercial level (or a change in configuration) can easily trigger a cascading change of thousands of design structures. (Tiihonen, et al., 1998)

Engineers usually comprehend a product, being part of a product family, as a generic constitutional structure. These structures can be seen as the the set of parts or characteristics. An essential part in definining these structures is the function of the structure and as the structure is consisting of elements (materials, dimensions ,etc) and relations in a hierarchical manner, each function and sub-function in the structure is defined by decisions that further limits the subsequent functions of the structure. (Pulkkinen, 2007)

2.3 Product configuration

Configuration is a word which has two different meanings depending on how the aspect is viewed. Configuration can be an activity or an object (result). The configuration activity can be seen as a task for configuring a product and the configuration object should be treated as a result of the activity. (Pulkkinen, 2007)

The word configuration is a word that is not necessarily only related to certain activities in different functions in manufacturing companies. In fact, the actual definition of the word "configuration" according to Random House Unabridged Dictionary (2019) is "the relative disposition or arrangement of the parts or elements of a thing" or simply "conformation" which is the synonym for configuration. Examples of the definition of configuration in chemistry would be "*an atomic spatial arrangement that is fixed by the chemical bonding in a molecule and that cannot be altered without breaking bonds*" (Random House Unabridged Dictionary, 2019). Or in computer science "*the way a computer or computer system is put together; a specific set and arrangement of internal and external components, including hardware, software, and devices*" (Random House Unabridged Dictionary, 2019).

Based on the dictionary definitions mentioned above Pulkkinen (2007) has defined four different aspects of configuration which are interpreted below.

1. A configuration is a grouping of components and the components' relation
2. A configuration is a special arrangement of the set of possible arrangements (defined by configuration rules)

3. A configuration has a purpose. A given configuration implies a certain use. E.g. a computer with very high GPU performance might imply configuration for playing high demanding computer games.
4. The purpose of a configuration can be similar as the purpose of other configurations (the components can be similar or related). E.g. a computer configured for video editing might have similarities with a computer configured for gaming due to the high demand on GPU performance.

Product configuration can be understood as a method to handle variance in product features to meet individual needs of every customer in a cost-effective way. The configurability of a product is supporting the re-use of large-scale component data and reuse of processes in favour of increasing the product variety (Kropsu-Vehkapera, et al., 2011). Sääksvuori & Immonen (2002) says that "[Product] *configuration is a method of arrangement*". This is aligned with the first aspect of configuration that is defined by Pulkkinen (2007).

Pulkkinen (2007) also states that configuration is a way to define products in an assemble-to-order (ATO) business model. The same can be applied to the CTO business strategy where the main differece is that CTO does not involve stock keeping of assemblies or modules. On the other hand Pulkkinen acknowledges that this has been challenged by Brown (1998) who also states that it would be possible to do configuration in a engineer-to-order (ETO). Brown (1998) says that the design part of configuration is usually thought of as "*Refining abstract components by specifying the values for their attributes*". However, Brown (1998) says that there are exceptions to this e.g. " ..*when the components have parameters that need values, but no additional refinement is needed for the relationships between components.*" Pulkkinen on the other hand considers Brown's statement to be for a make-to-order process since the parametric design can be regarded as a sub-task of configuring.

When speaking in the terms of information technology, a product configurator is seen as an application that manages the structure of a product and the variations of a product (Sääksvuori & Immonen, 2002) which is the second aspect defined by Pulkkinen (2007). As mentioned earlier, Tolonen (2016) has highlighted the importance of the commercial definition of a product portfolio. Not only the word configurations can have several meanings, also the word "configurator" can quite often be differently understood depending on the kind of organization you are speaking two. There are basically two high level aspects of a configurator: Sales configurator and product structure configurator (Sääksvuori & Immonen, 2002). In the subsequent chapter, the two different levels are going to be reviewed in more detail.

2.3.1 Sales configuration

A sales configurator can be seen as a higher level configuration that controls sales properties of a product and all the rules that apply to these sales properties. Rules (or constraints) in a sales configurator can be considered as formal, logical or mathematical mechanisms that define the allowed combinations of parts for a product but also prevents invalid combinations of parts (Tiihonen, et al., 1998). An example of a sale configurator rule would be that a car manufacturer has defined a constraint between a certain type of engine (a 70 kW engine) and an automatic gearbox. In other words, if the engine has the sales item property value of 70 kW, then the gearbox sales item property values must be different to automatic. The origin for such rules can be both technical as well as a strategic decisions. In other words, there might be technical complications making the enigne incompatible with an automatic gearbox or there might be a business decision not to sell the the automatic gearbox in combination with the 70 kW engine. (Sääksvuori & Immonen, 2002)

The output of a sales configurations is a structure that is commonly referred to as sales structure which in practice incorporates the group of features (derived from customer requirements) that defines the technical strucutre of the product. (Sääksvuori & Immonen, 2002)

An example of the output (on a feature level) from a sales configurator for a car would be:

- Engine: 70 kW
- Transmiassion: Manual
- Drive: 4WD
- Color: Red

The above mentioned are the selected features done in a sales configuration. The selected features can be selected among other available features given that configuration rules are satisfied. Below a sample structure as Sääksvuori & Immonen (2002) have presented it.

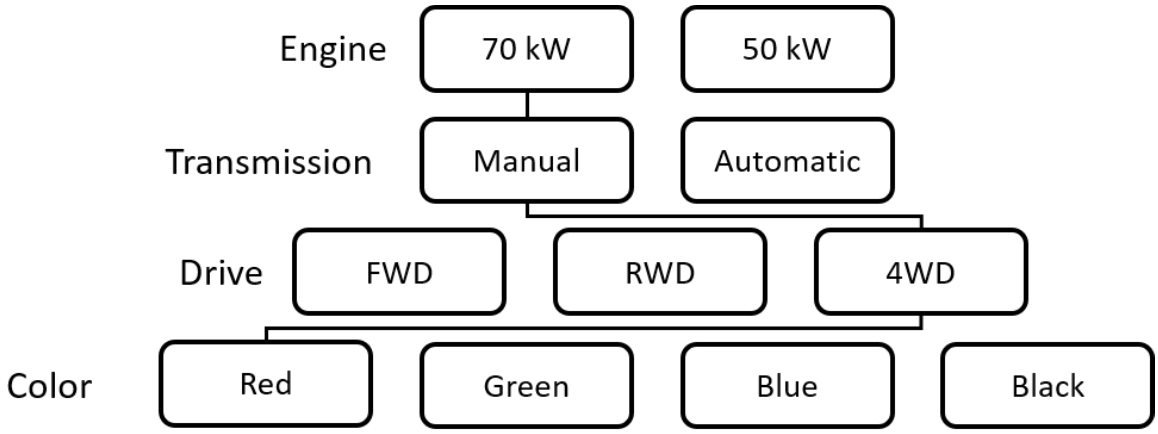

Figure 6 Sales structure as presented by Sääksvuori & Immonen (2002)

The configuration activities and the outcome structure as described above by Sääksvuori & Immonen (2002) is valid in cases where the product is defined to be delivered as one single entity. The structural problems that can occur in sales phases are when there are more products added to the list of sellable items or the scope of supply or in other words, when the scope of supply cannot be treated as single entity.

As Tolonen (2016) describes, a product configuration can be a bundle of different configrable products satisfying the customers individual needs instead of a single configurable product. Kropsu-Vehkapera, et al. (2011) also states that the first step is to identify the sellable items (which can consist of several products) and do the configuration "*..on a higher level*". An example where additional products can be added to the the car example would be the addition of service agreements or insurance that is jointly sold with the car. Additional sellable items like the previously mentioned is often referred to as "optional items" in literature e.g (Stark, 2011) but Tolonen is consistent in his usage of the term "product configuration" meaning a configuration of multiple products or multiple sellable items.

Combining the concepts presented by Tolonen (2016) and Sääksvuori & Immonen (2002), the information flow and related structures can be defined in the same manner but taking into account that the scope of supply will be realized by a range of products which in the end have their own technical aspects.

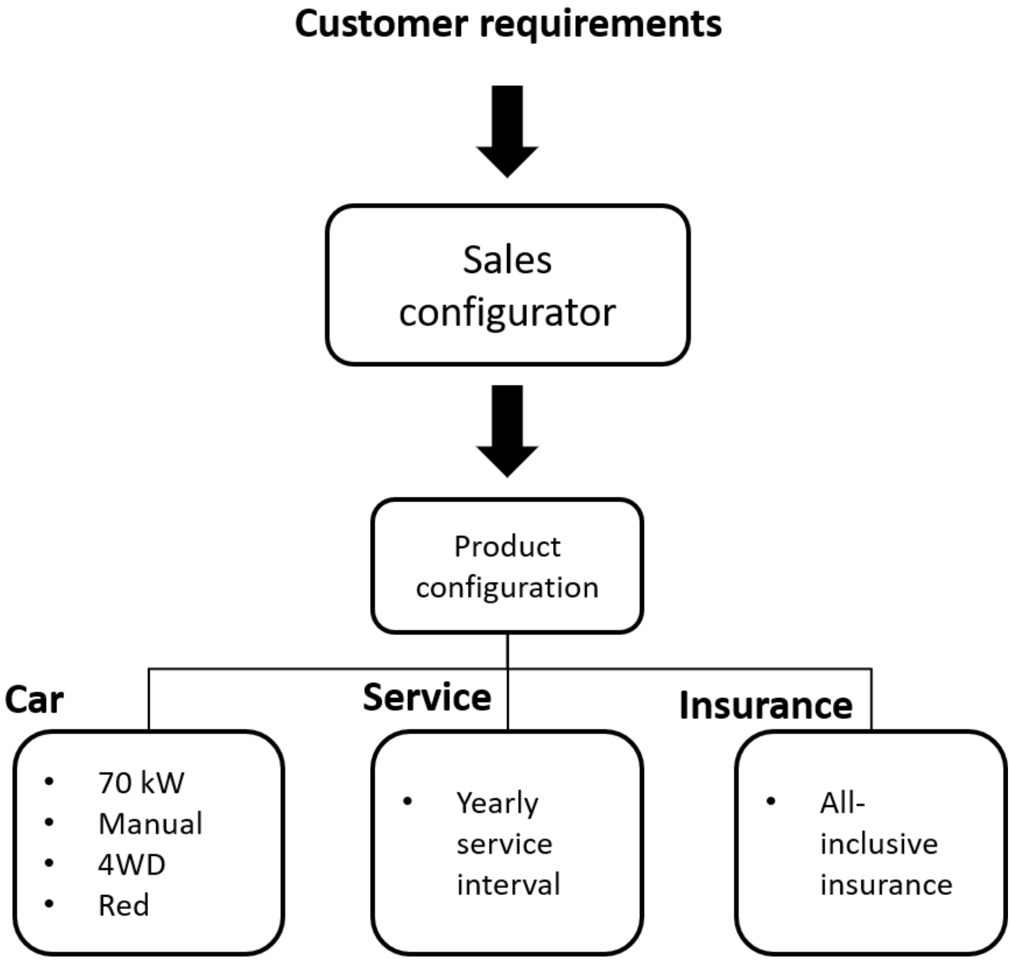

Figure 7 A Sales configurator output

In figure 7 above, the list of sales items (or scope of supply) is realized by translating (using a sales configurator) the customer requirements into a range of product variants where each variant has an underlying product structure describing the product variant features that can be used to meet customer requirements.

In the case of the car example above, a customer's requirements could be something like the following. A car with a high performing engine, off-road properties, manual gearbox and red in colour. (Sääksvuori & Immonen, 2002) says that a functioning product lifecyle management (PLM) system is a prerequisite for a sales configurator to work. A PLM systems can handle the product variants, its strucutre, its price information and related documentation. By having a functioning PLM system with a sales confiugrator integrated (or part of), customer requirements can easily be met by selecting from available features. A sales configurator also ensures that only valid combination of features are selected for a product configuration. As pointed out several times, Tolonen (2016) states that all customer requirements can not always be met by the configuration of a single sales item (or product) but instead a number of configurable products are needed. In the previosuly mentioned car example, a customer might also have requirements such as: Guaranteed performance of X number of years, and security in the terms of insurance. These requirements can be translated as the addition of the sales items "service agreement" and "insurance".

As previosuly mentioned, a product can consist of hardware, software, services and documention or any given combination of these (Stark, 2011), (Tolonen, 2016), (Kropsu-Vehkaperä, 2012) and (Sääksvuori & Immonen, 2002). Thus the complete package of a car, a service agreement and an insurance could be seen as a configured product but the distinction of treating them as separate sellable items is due to the definition of the product portfolio. Each of the items in the sales items list are separately sellable items that might be valid for selling and purchasing individually. For example, you can purchase a service agreement X years after you have purchased the car which is also an applicable logic for the insurance. The sales items service agreement and insurance might also be valid items to include in a scope of supply for other car configurations.

Thus, the outcome of a sales configurator is the sales structure which is also commonly referred to as the scope of supply or the list of sales items. In order to deliver this structure from a sales configurator, a product structure is needed that defines the tehnical infomration for each sellable item on the commercial level.

Mittal and Frayman (1989) has pointed out that there are three important aspects of configuration which are:

1. One cannot design new components during a configuration task
2. Each component is restricted in advance to only be able to "connect" to other certain components in fixed ways. I.e. they cannot be modified to get arbitrary connectivity and that
3. The solution (the configuration outcome) specifies not only the components used in the configuration but also how the relate to eachother

The three aspects that are defined by Mittal and Frayman are presented in the manner of a tehcnical product configuration. However, considering the theory presented by Tolonen (2016), the same can be applied on a higher (commercial) level of configurtion. For example: One cannot configure a new sellable item, each (available) sellable item is restricted in advance to only connect to other certain sellable items and the the solution (or the sales structure) specifies not only the sellable items included but also the relation of those items.

Applying Tolonens logic on Mittal & Fraymans configuration aspects, it becomes evident that the commerical definition of the sellable items as well as the rules and constraints between these items needs to be defined in order to generate a sales structure that can be used as an input for a technical (product structure) configuration. In other words, a sales configurator can only give defined sellable items as output as one cannot define new sellable items during the configuration task.

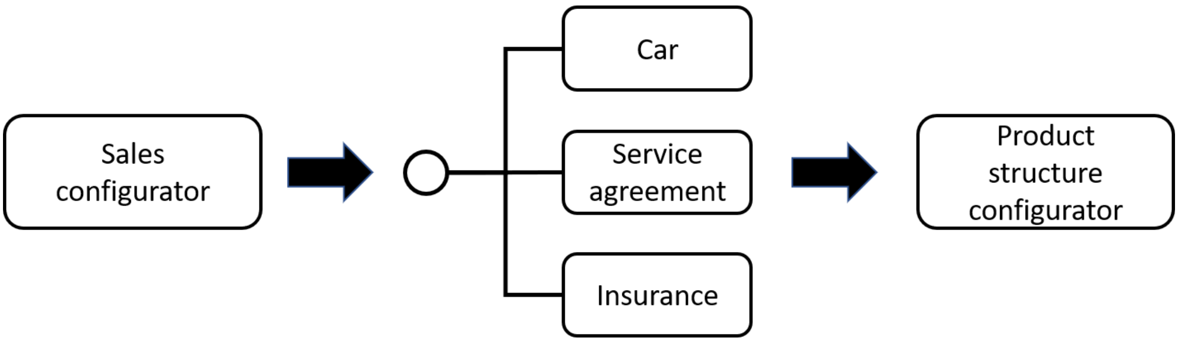

Figure 8 Information flow from a sales configurator to a product structure configurator

2.3.2 Technical configuration

Technical configuration is different from sales configuration in many ways. As mentioned in the previous chapter the sole purpose of a sales configurator is to select the possible combination of sales features. A technical configurator, or a product structure configurator as a more descriptive name, is used to generate a product structure based on the selected features in a sales configurator (Sääksvuori & Immonen, 2002).

If a PLM system has an in-built functionality to support product structure configuration, a physical representation (in the form of assemblies or BOM's) can be created with items and item variations that fulfil the properties of the selections made in a sales configurator (Sääksvuori & Immonen, 2002). This requires that the items and item variations used to create the physical representation can be mapped or related to the product features as they are defined in a sales portfolio and to the way those features are handled in a sales configurator. In other words, the physical representation needs to be associated with a product variant and product version that is available in the sales portfolio.

In order to generate a product structure by the means of using a product structure configurator, the product structure configurator needs to be fed with the output of a sales configurator as its input as described in figure 8. If the sales properties can be mapped to a product structure, the product structure configurator would produce a product structure matching the selected features in the sales configurator as its output (Sääksvuori & Immonen, 2002).

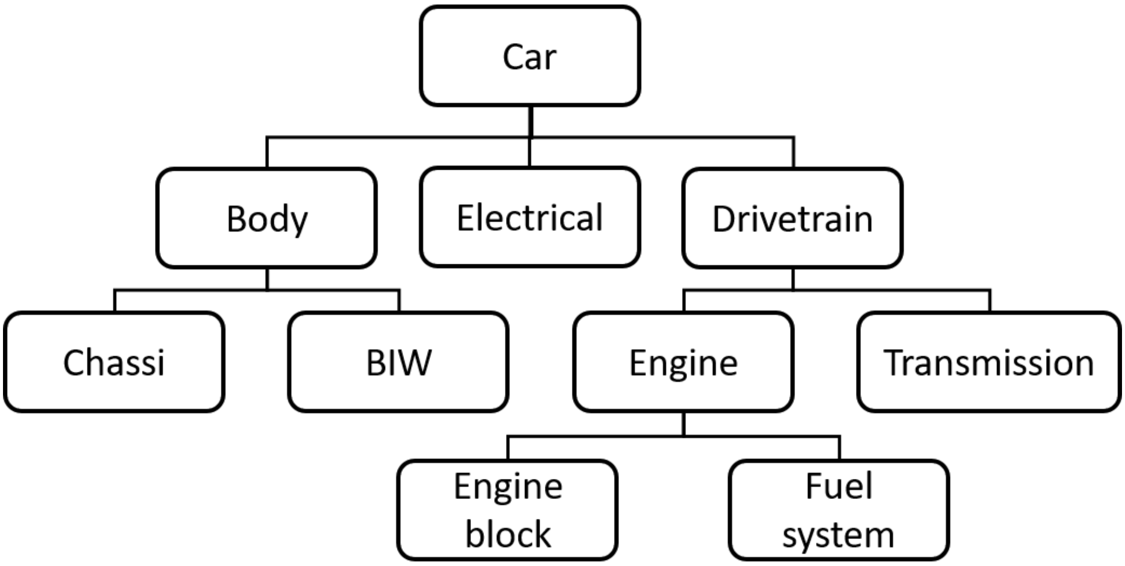

Figure 9 Technical product structure as described by Sääksvuori & Immonen (2002)

The product structure output defines the assemblies of the product and adds meaning to the product by the definition of the BOM (or BOM's) used to realize the product (Stark, 2011). A product can be built of several assemblies and several BOM's such as the Engineering Bill of Materials (EBOM) that is defining all the items that are used to make the end item. A BOM can be simplified as a way to describe an item being used to make another item which in turn is used to make a third item and so on (Stark, 2011). In other words, the BOM is describing the components used, how they are related and how they are assembled.

In order for a product structure configurator to generate a product structure based on the sales properties, a connection between these properties and the physical representation is needed, i.e. the physical representation of a product needs to be linked to other aspects of the products such as the functionality of the product (Stark, 2011) (Sääksvuori & Immonen, 2002). This linkage to other aspects (such as the functionality) can be used to select correct product structure based on the sales properties. This connection might prove hard to manage since each selection of properties in the sales configurator affects the product structure. For example, the car example with a combination of two engines, two transmissions, three different drive types and four colours will alone produce a total of 48 unique product structures. Tiihonen, et al. (1998) says that a more generic technical structure is preferred over a model using pre-defined fixed design modules for configurable products due to the reason that on the latter case, the combinations might be vast for complex products.

Similary as during sales configuration, Mittal & Frayman's three aspects of configuration can be applied on a product structure configurator. If the output structure from a sales configurator cannot be used, then the product structure cannot be generated as there are no components associated with the features selected in a sales phase. This requires new design, new defintion of constraints and new definition of relation between design components where none of these activities are part of a configuration task.

Stark (2011) states that one of the main benefits of PLM is the business improvement through the increase of part reuse, the increase in product traceability and the support for 100% configurability. A product structure not capable of supporting the aspects of sales configuration and product structure configuration are endangering e.g. the benefit of increased part reuse since the two structures (sales structure and product structure) cannot be associated with each other meaning that there might be new designs needed in the product structure to meet the customer requirements. It might also increase the risk of project overrun due to additional time needed for engineering change activities (Stark, 2011).

If the structures are segregated, the association of sales featrues with design modules becomes increasingly hard to manage. Different organizational functions might have different descriptions or namings for the same thing (e.g. different names on a product feature) and the translation of these namings might be tricky to handle. Mello (2002) has described this as a siloed way of working.

Stark says that the product architecture links the physical representation to other aspects of the products such as the functionality which is in turn used to determine the sales arguments.

2.4 Theory synthesis

When speaking of products, it has by the literature review of this thesis become evident that there is a different need of product information for different organizational function within a company. The product information is usually handled in a PLM system where the core functionalities have been summarized by Sääksvuori & Immonen (2002) as:

- Item management
- Product structure management
- Document management
- Change management
- Retrieval of information
- Workflow and distribution management

All of the above-mentioned categories are of great importance to properly handle product information throughout its lifecycle. However, given the limitations of this thesis, the theory has focused mainly on item management, product structure management and retrieval of information. In addition to this, product definitions and product portfolios have been covered by the literature review.

Reflecting over the three research questions that were given in the beginning of this thesis, the theory review has yielded main findings that will help answer those questions.

Finding	**Description**
Product definition	It is inevitably important that the products are defined in an indubitable way and the definition of the product remains the same throughout an order to deliver process eliminating risks of project overrun time

	due to reduction in changes later on the order to deliver process
Product portfolio	Once the product definition is set, the products need to be defined in a product portfolio taking into consideration the different levels of information associated with the products and the relation of the products to other products and applications e.g. different market segments.
Product structure	In order to be capable of retrieving information of a product, the product needs to be described in a structural way taking into consideration the information of the product and its relations. In other words, the product structure explains how a product is generated using items.
Product configuration	A product configuration can be viewed upon as way to group items and components to form a specific type of product i.e. a product configuration. The product configuration can be done in several levels such as sales configuration and technical configuration where the product structure serves as an important input.

3. Method

In this chapter I will be focusing on describing the selected research method for assessing the current state of product definition, product portfolio, product structure and product configuration in the product lines that were selected to be the candidates for this master thesis.

According to Trost (1993), selecting a quantitative or a qualitative research method is directly linked to the questions needed to be answered. Put differently, the purpose of the study gives the research method. If, for example the intention is to find frequencies of a thing, then a quantitative method is preferrable where one has to make sure the sample is representative. One can simplify and say that if it is a question of how often, how many or how usual it is, then a quantitave study is an appropriate research method (Trost, 1993). If the intention, on the other hand, is to increase the understanding or to find certain patterns, then a qualitative study is the preferreable method (Trost, 1993).

As the intention with this thesis is to answer three research questions, by getting an increased understanding of the processes used, the selection of a quantitative research method was deemed inapproporiate. Instead a qualitative research method was selected in the form interview sessions with persons from different business lines having roles and responsibilities related to the area of investigation. It is arguable whether this study could have been conducted in a quantitative manner or not due to the amount of interview sessions conducted. Even though the number of interviews, the qualitative method was selected as a quantitative method was considered not to give enough details increasing the risk of being incapable of finding problematic areas and patterns.

The product lines that were chosen as candidates were carefully selected (based on a set of selection criteria) amongst several product lines in the company in order to have a set of product lines representing different stages of maturity in regard to product definition, - portfolio, -structure and -configuration. The selection criteria for selecting the representative set of product lines is based on the outcome of the literature review as well as on a previous study done on productization, product management and product portfolio management done by Linda Lushaj (2018)

The criteria for selecting the product lines were consisting of the following:

1. The product lines operate according to CTO or ETO
2. The product line has a defined product portfolio (Yes/No)
3. The product line uses a central PLM system for maintaining the product structure (Yes/No)
4. The product line has product configurators in use (Yes/no)

3.1 Interviews

The assessment of the current state was done in a qualitative manner consisting of interviews with three persons from each product line selected as candidate. The persons, in turn, interviewed were representing different organizational functions within the same product line. The roles of the persons interviewed were selected in accordance with the research questions and the literature review and the roles of those persons are:

1. Portfolio/Product manager
2. Back-office sales representative
3. Project execution engineer

The roles and responsibilities of the persons were selected in the way that they represent an organization that is involved in product structure and information in different phases of a project lifecycle starting with product portfolio management and ending with project execution and delivery. The title of the persons interviewed were deemed to be of minor importance as persons with similar organizational roles and responsibility areas might have different titles within the company.

The interview sessions were semi-structured sessions. The degree of structuring can have two different meanings, where one means that a structured session has questions with given alternatives for the answers and the other means that the questions themselves are structured (predefined) but without alternatives (Trost, 1993). The latter one was used in this study. The interview sessions were mostly conducted face to face but on some occasions also virtually over Microsoft Skype due to the geographical distance between the interviewer and the interviewee. A set of interview questions was used where the interview questions were not sent to the interviewees in advance. The interviews were a deep-dive into the current ways of working and the tools and information at hand. The decision to not send the questions in advance was taken to get answers as accurately as possible. If the questions would have been sent in advance, the risk of people looking up information beforehand would increase. The risk of people answering the questions in the way of how it should be rather than how it is would also be increased if the persons would have the possibility to prepare for the session. To also lower the risk of people giving politically correct answers, the interviewees were clearly informed that the answers given would be strictly anonymous which is an important element (Trost, 1993). The anonymity was clearly stated in the personal invitation sent to each interviewed person and was repeated in the beginning of the session. It was also emphasized (both in the invitation and in the beginning of the session) that recordings would be made which would be destroyed after the thesis is done and that actions would be taken to ensure the answers to the interview questions could not be traced back to an individual. During the interview sessions the facilitator was taking notes of the answers given to each question and the notes were shared with the interviewee at the end of the session to secure correct understanding of the answers. In addition to that, the notes were also sent to the interviewees and they were given the opportunity to correct possible misunderstandings.

When making questions for an interview session, there is always the risk of unintentionally asking leading questions as we are very used to asking leading questions in our daily lives (Trost, 1993). To avoid the unintentional introduction of leading questions, the set of questions was first made based on the literature review and a review of the questions was made with the mentor after which a revision of the questions was made. Due to the semi-structured characteristics of the interviews, follow-up questions were sometimes asked to secure correct understanding of the answers. The follow-up questions were given in the form of "how do you mean?" and "could you elaborate on that?" to avoid having the interviewee answering yes to something that was only 90% correct (Trost, 1993).

The notes take during the interview sessions were in several cases fairly long. In order to get the core message of the answers a method which is referred to as "sentence concentration" (Kvale & Svend, 2010) where the intention is to formulate the answers in a shorter way capturing the key message. This method can be used to gather common sentence units which can be compared to each other and subject for further interpretations and analysis (Kvale & Svend, 2010).

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5. APPENDIX

Interview questions

1. Product definition
    a. What is in your view a product (within your organization)?
    b. Where is the product definition stored?
        i. Who creates the definition?
        ii. Who owns the definition?
        iii. Who has access to it?
        iv. Is the definition common for the whole organization?
2. Product portfolio
    a. How many products are there in the product portfolio (within your organization)?
    b. How is the product portfolio structured?
        i. Application?
        ii. Market segment?
    c. Where is the product portfolio stored?
    d. Are there different levels of information in the product portfolio?
        i. If yes, what levels?
3. Product structure
    a. Are there different variants of a product?
        i. If yes, can the variants share modules?
    b. Are there different versions of a product?
        i. If yes, how are versions handled?
4. Product configuration
    a. Considering your organization, what is (in your opinion) a product configuration?
    b. Are there configurable elements to the product(s) in the portfolio?
        i. In case there is, are there configuration rules defined for the configurable elements?
        ii. Are there configuration rules defined between products?
    c. Are there several levels of configuration?
        i. If yes, what levels?
    d. Who owns the product configurator?
5. Product information flow
    a. In short, describe product information in a sales process
    b. In short, describe product information in a project execution process
    c. In short, describe how information is transferred to other organizations in a sales – delivery process
6. Challenges
    a. From your organization's viewpoint, describe the biggest challenge in regards of product -definition, -portfolio, -structure, -configuration and -information flow.