



SALES AND PRODUCT CONFIGURATION OFF MASS CUSTOMIZED AUTOMIZED VEHICLES

Lappeenranta–Lahti University of Technology LUT

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ABSTRACT

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Sales and product configuration off mass customized automated vehicles

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The goal of this thesis was to provide a framework of how a complex Automated Guided Vehicle product family should be modelled into Configure Price Quote (CPQ) software without losing the flexibility to quote customized solutions and simultaneously develop the order-delivery process efficiency. The thesis was made for Mitsubishi Logisnext Europe.

In the literature part of this work common ways to improve ETO processes, mass customization principles, product architecture, and product configuration were studied. Semi structured interviews were used to acquire knowledge about the current order-delivery processes and its improvement points. Value analysis was used for defining optimal level of configuration for the product family. The configurability of the product family's generic product structure was analyzed statistically.

The optimal level of configuration was pointed out to be the hybrid CTO approach for the product family. Based on the statistical analysis it was noted that the current generic product structures aren't serving the project engineering department as would be optimal. The configuration process of the product family was divided into two steps. Based on this study it can be stated that the implementation of CPQ software enhances the order-delivery process a lot by reducing many manual operations and offers a lot of potential for future improvements.

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Tämän diplomityön tavoitteena oli selvittää, kuinka kompleksinen automaattitruckien tuoteperhe tulisi mallintaa myyntikonfiguraattorihjelmistoon menettämättä joustavuutta tarjota räätälöityjä ratkaisuja ja samalla kehittää tilaus-toimitusketjun tehokkuutta. Työ tehtiin Mitsubishi Logisnext Europelle.

Työn kirjallisuusosassa tutkittiin yleisiä tapoja parantaa ETO-prosesseja, massaräätälöinnin periaatteita, tuotearkkitehtuuria ja konfigurointia. Puolistrukturoiduilla haastatteluilla hankittiin tietoa nykyisestä tilaus-toimitusketjusta ja sen kehityskohteista. Tuoteperheen optimaalisen konfigurointitason määrittämiseen käytettiin arvoanalyysiä. Tuoteperheen geneerisen tuoterakenteen konfiguroitavuutta analysoitiin tilastollisesti.

Optimaaliseksi konfigurointitasoksi määriteltiin hybridi-CTO ympäristö. Tilastollisen analyysin perusteella havaittiin, että nykyiset geneeriset tuoterakenteet eivät palvele projektisuunnitteluosastoa optimaalisesti. Tuoteperheen konfigurointiprosessi jaettiin ohjelmistossa kahteen vaiheeseen. Tämän tutkimuksen perusteella voidaan todeta, että myyntikonfiguraattorin käyttöönotto tehostaa huomattavasti tilaus-toimitusketjua vähentämällä monia manuaalisia toimintoja ja tarjoaa paljon mahdollisuuksia jatkokehitykseen.

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SYMBOLS AND ABBREVIATIONS

Abbreviations

AGV	Automated Guided Vehicle
aBOM	After sales Bill of Materials
ATO	Assemble-to-Order
BOM	Bill of Materials
CO	Customer order
CPQ	Configure-Price-Quote
CTO	Configure-to-Order
eBOM	Engineering Bill of Materials
ERP	Enterprise resource planning
ETO	Engineering-to-Order
IoT	Internet of Things
MC	Mass Customization
mBOM	Manufacturing Bill of Materials
MTO	Make-to-Order
MTS	Make-to-Stock
PDM	Product Data Management

Table of contents

Abstract

Acknowledgements

Symbols and abbreviations

1	Introduction	8
1.1	Motivation and background of the study	8
1.2	Goal of the study	10
1.3	Research problem and questions	11
1.4	Methods and scope of the work	11
1.5	Order delivery process different point of views.....	12
1.6	Contribution	14
2	Theoretical background	15
2.1	Mass customization.....	16
2.2	Product architecture for mass customization	20
2.2.1	Product architecture of the case company	23
2.3	Product configuration.....	26
2.3.1	Configurable products.....	28
2.3.2	Different manufacturing approaches	29
2.3.3	Moving to Configure-to-Order strategy.....	31
2.3.4	Tacton CPQ configurator.....	34
2.4	Current order-delivery process.....	35
2.4.1	Sales configuration	35
2.4.2	Technical configuration	37
2.5	New order-delivery process	40
2.5.1	Sales and technical configuration	40
2.5.2	Managing the customizations	42
2.5.3	Impacts to factory operations.....	45
2.6	TOWS Analysis	46
2.7	Value analysis	48
2.8	Summary of theory.....	49
3	Research methods.....	52

3.1	Applied research methods	52
3.2	Value analysis	53
3.3	Statistical analysis	54
4	Results and analysis.....	55
4.1	Value analysis	55
4.2	Statistical analysis	56
4.2.1	General modules	56
4.2.2	Straddle modules.....	61
4.2.3	Counterbalance modules.....	62
4.3	AWT product family configuration	64
5	Conclusions and discussion.....	69
5.1	Comparison and connections with former research	69
5.2	Objectivity.....	70
5.3	Reliability and validity	70
5.4	Assessment of the results and sensitivity analysis	70
5.5	Key findings	71
5.6	Novelty and value of the results.....	73
5.7	Topics for future research	73
6	Summary.....	74
	References.....	76

1 Introduction

The customization of products and services is becoming the rule rather than an exception these days since competition is higher than ever and customers are more aware of what markets have to offer. Customization is a great way to stand out from the competitors and to give the customer the best possible solution for their needs. Customization also causes problems for the manufacturing companies especially in quotation process: sales personnel and customers can have a lot of trouble trying to find the right solution for their needs because of the huge variety of options and therefore possible configurations. There is a growing need for help in navigating between the options and showing the ways of how selecting one option may restrict or open the choice of another option. (Sayer, 2021.)

Configure-price-quote (CPQ) software can automate the order quote process for customized solutions which can be time consuming and the risk for mistakes is high. CPQ software is configuring a customized solution according to the customers' needs from the company's product range. The CPQ process is a great way to boost the sales of mass customized (MC) products as it helps the sales personnel to identify the correct solutions for products, determine the price of the whole solution and therefore produce an exact offer for the customer. (Sayer, 2021.)

This master's thesis studies how the order delivery process of mass customized automated vehicles can be improved using product configuration.

1.1 Motivation and background of the study

The case company of this study is producing high-tech logistic solutions including a wide range of forklifts, Automated Guided Vehicle (AGV) solutions, racking, Internet of Things (IoT) systems and customer tailored packages of services. All the delivered projects are designed to give customers the perfect logistic solution for their needs. The company operates internationally and about 95 % of its sales come from exportation. Logistics is a highly competitive field globally and there are many megatrends occurring like e-commerce, digitalization, and automation & electrification. The solutions provided by case company are directly related to these megatrends and they intend to seamlessly combine various high-tech

solutions into mechanical solutions. This vision is concretized by AGV systems that the company designs and manufactures in Finland with more than 40 years of experience and over 2000 delivered projects globally. AGV systems are automatic logistic solutions in transportation and storage of products. The company has industry best practices and expertise in providing AGV systems for manufacturing, warehousing, tire manufacturing, paper and board manufacturing, food and beverage, and packaging segments. (Mitsubishi Logisnext Europe Oy, 2021.) In figure 1 is shown the case company's AGV model fleet.



Figure 1. AGV model fleet (Mitsubishi Logisnext Europe Oy image bank).

The case company produces vast amounts of quotes every year and since all the projects are designed to give customers the best possible solution, the quotation needs to be fitted according to the project. This requires a lot of knowledge and experience from sales personnel since the quotation tool in use does not have enough rules and restrictions. This naturally increases the risk for human errors in quotation phase and can cause inconsistency in quotes. One of the problems that the case company needs to solve is also the large number of product options and their compatibility between different product models that has not been clearly defined by regulations. The quotation phase would be more optimal in a way where the sales personnel wouldn't need to know so much about the technical modules of

the product but they could focus on selling the products and features selected by them would automatically produce the right technical solution using product configuration.

Companies that manufacture customized products are facing many problems with offers but the ones mentioned above are most urgent for the case company. The case company needs to overcome these problems if it aims to grow its sales and remain a competitive player in the global field of logistics. One of the biggest trends to tackle the problems in quotation phase of mass customized products is configuration software. Sales configurators are making it possible to automate the offer production and therefore, optimize the accuracy of the quotation, pricing and most importantly minimize human errors. Product configurators allow a complete definition of all possible outcomes and variations by creating, using, and maintaining product models. To start the configuration, all relevant knowledge about the product needs to be modelled in a form that can be included in the configuration system. (Hvam et al. 2011, 597.) The product architecture needs to be structured in a certain way to make configuration of products possible and to reach their full potential. One highly used product architecture in the industry is modular product architecture which is also used in case company. (Hvam et al. 2011, 596.)

The number of variations in the product needs to be considered in such that there are enough options for the markets to attract the customers but also keeping in mind the profitability and manufacturability of the product. Standard products have the biggest margins and lowest lead times, and these are the things desired by any manufacturer. The case company also manufactures customer tailored products that are completely outside of the regulations and restrictions of allowed combinations of the product variants. This part also needed to be included in the product configurator for making the quoting and ordering of these special projects available.

1.2 Goal of the study

The goal of this thesis is to provide a framework of how a complex AGV product family should be modelled into a CPQ configuration software. Keeping the needed flexibility of engineering-to-order (ETO) environment to be able to quote customer specific customizations but also developing the order delivery process more into Configure-to-Order (CTO) to obtain the benefits that the CPQ software is providing. The task of the configurator

is to automatically offer suitable standard solutions from the product range to which options requiring customer specific customization can be added. This work also produces information to enable configuration, to lock the technical solution to product feature codes and to create the modules in the product configurator.

1.3 Research problem and questions

The research problem of this work is related to improving the efficiency of the order delivery process by enabling CPQ software in quotation processes. Currently, to be successful, the salesperson needs to be very experienced and precise in making the choices, and the risk of mistakes is high. The current quotation tool does not contain enough rules and limitations. For example, cross selection of battery sizes between different machine types is possible.

The aim is to change the process in such a way where the salesperson can focus on selling the products, and the features that they select would automatically produce the right technical solution through configuration if possible. The configuration software would guide the quotation process by clearly representing the product family being configured and what combinations of modules are possible. The problem is also the large number of product options, and their compatibility between different product models is not currently clearly defined by regulations, and how the customer specific customizations can be quoted through the configurator software. To study the problem described following research questions are formed:

What would be the optimal level of configuration for complex AGV product family to develop the efficiency of order-delivery process without losing the ability to quote customer specific solutions?

How are rule deviations managed in CPQ software so that the mixtures of different modules prohibited by the code can be configured to meet customer needs?

1.4 Methods and scope of the work

To answer these questions, in addition to literature study, interviews, value analysis and statistical analysis are used. Literature study is the theoretical background of the work. It

consists of common ways to improve ETO process and its quotation phase, mass customization principles, standardization, and product configuration. To acquire the knowledge about current quotation process, product architecture and needs for the options in sales configurator semi-structured interviews are used. Value analysis is conducted to find out the optimal level of configuration for the product family. Statistical analysis is done to determine how the product family can be modeled into the CPQ software and to point out improvements to products modularity. The interviewees work in sales and product management or in a related field. This work includes only the work steps from the creation of a customized offer to the technical solution of the design and the result which is the customized manufacturing Bill-of-Materials (mBOM) of the product.

1.5 Order delivery process different point of views

The order delivery process can be seen very differently depending on the person's point of view. For example, if asking from sales manager, engineer, production clerk, and customer how do they imagine the order delivery process of the case company the answers will probably vary a lot. It is important to find out everyone's perspectives on the matter, so that the process can be developed in such a way that it serves all parties better. For this reason, a group interview inside the company was arranged to discuss the matters affecting the order delivery process and how it could be improved. In the interview there were participants from sales department, engineering, and manufacturing, all working in senior or management positions.

From the sales point of view the current order delivery process biggest improvement point is the fact that the options and data available in current sales configurator cannot be fully trusted since it is in no straight relation to either product data management (PDM) or enterprise resource planning (ERP) systems. The data and costs in the sales configurator should be realistic and the options and restrictions there would then guide the work of the sales manager. It should be clear that what can be offered as standard options and what can be customized according to beforehand agreed restrictions, for example if custom length navigation mast is needed the configurator would state the lengths that are available and the cost of that customization. It is accepted that customizations cannot be avoided. They will always be needed to be able to find solutions for customers and to stand out from

competition, but they should be restricted in more detail that what makes sense to quote. The sales configurator should be guiding the sales process, if the solution is not found by the configurator, then it isn't quoted for customers. Options available for products should also be productized better and have indications of what are standard pre-engineered solutions and which engineering-to-order options.

It was also noted that the maintenance of the current sales configurator is manual and therefore insufficient. The options available are not always the same as what can be really quoted, because the information flow from engineering to sales about the productized options isn't always optimal and it can take too long to get the new productized option into sales processes. Defining the costs of AGV projects order delivery processes precisely is impossible since each case is individual, for example commissioning, transportation, used subcontractors etc. but one thing that can and should be optimized is the costs of the vehicles since they are usually representing around 60-70 % of the whole project delivery price. The ways to improve the pricing of the vehicles that were raised in the interview were, for example, automatic feedback of the realized costs of the delivered vehicles individually. And when considering the costs of customization, the available options could be categorized according to the resources and costs needed manufacture and engineer it, since now these costs are all estimated from history, and they can vary lot.

From the engineering point of view the process starts from a project kickoff where the project manager introduces the case and the engineering needs for the project are discussed. The engineering of the vehicle starts when the options in sales quotation and needed customization are handled and translated into technical solutions. The biggest problems raised by engineering are also the detachment of the current configurator from PDM and ERP systems. From an engineering point of view the PDM should be the guiding factor and master for the data existing in the configurator and factory ERP, meaning that the sales options available would be based strictly on technical solutions existing in PDM. It was also noted that the current order delivery process is built on too much manual work, and this builds up the risks for human errors and consumes lot manpower. Integrating the sales configurator to PDM and ERP was seen as a key factor to improve the efficiency and minimizing the errors during the process.

The productization of the AGV product family has been improved, but this isn't yet recognized in every department and system since the engineering structures aren't integrated

and manual maintenance of sales configurator has been mostly focused on costs and in more general, what can be quoted. The complexity and variety of products also affects the efficiency of manufacturing and procurement.

From the manufacturing point of view the biggest improvement points in the order delivery process is the lack of productizing the modules and the problems that this causes. Currently the manufacturing structure into factory ERP is constructed by engineers from two different sources, engineering configurator and PDM. Problem of this current process is that the engineering configurator has only a limited number of options and most of the modules are needed to design and integrate straight from PDM to ERP. All these modules coming from PDM are seen as custom modules in manufacturing even though they might be included in most of the cases. This is making it hard to predict the lead-times for vehicle assemblies and it is hard to standardize the assembly phase. Making this improved productization of the modules visible in the order delivery process would be great way to also make the manufacturing more efficient, the assembly phases could be standardized, standardizing the subcontracted modules, and reducing work steps, estimating the lead-times and costs could be done with much higher accuracy. Eventually growing the ordering capacity of the vehicles.

1.6 Contribution

This study is producing new information about configuring complex mass customized products and how the rule deviations can be managed to allow the ordering of customer tailored projects through configuration software. In this study the correct product architecture of large AGV product family is also being investigated and modified to best suit the modular product architecture method and configuration of the product family.

2 Theoretical background

This chapter consists of the literature study and theoretical background of this work. In the theoretical part is studied mass customization principles, product architecture that is supporting mass customization, product configuration, strategies when moving towards product configuration, the current order delivery process is described in more detail, and a new order delivery process flow is introduced. Also, the tools for analyzing the results of this work are introduced. In figure 2. the contents of this chapter are shown in the same order which they are presented in the text.

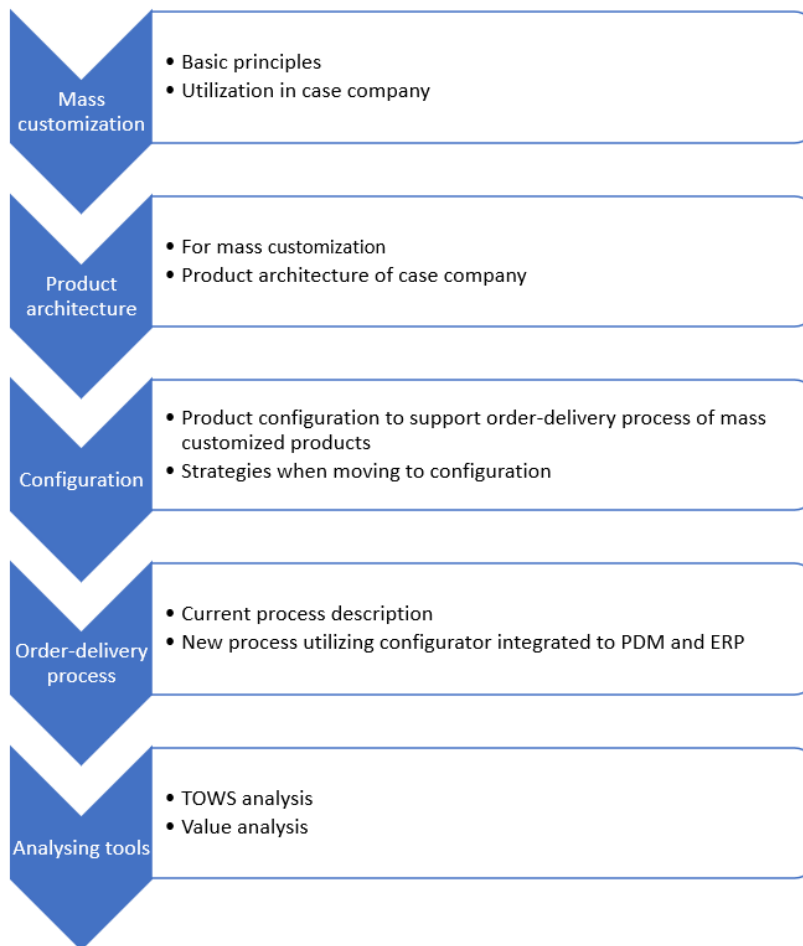


Figure 2. Theory background of the work.

Most important concepts that need to be understood after reading this chapter are mass customization principles, modular product architecture that supports the customization

processes, product configuration to manage the product range, and the impact of all these factors to order-delivery process of customized products.

2.1 Mass customization

The manufacturing industry has gone through many paradigms in its history. The first paradigm was craft production which started around two centuries ago. Local craft shops created unique products only from customer request without any manufacturing systems. Second paradigm is mass production which by the benefits of moving assembly lines could provide low-cost products with huge volume. One of the problems that came with mass production was the lack of variety in the products and as the global competition grew consumers began to have a lot more available choice and knowledge about the markets. Manufacturers responded to this by increasing the variety in using mass customization. The basic idea behind it is to provide customized products with high efficiency and reasonable prices. This was made possible by product family planning so that the products shared a lot of common components. The next manufacturing paradigm is seen as personalized manufacturing. Companies have always tried to maximize shareholder value in the past but recent studies have shown that the companies which focus more on the consumers have been performing better than the companies focusing on shareholders. This is leading to manufacturers involving the customers in creation and designing the products. In figure 3 below the different manufacturing paradigms are illustrated with volume variety relationship. (Hu 2013, 3-4.)

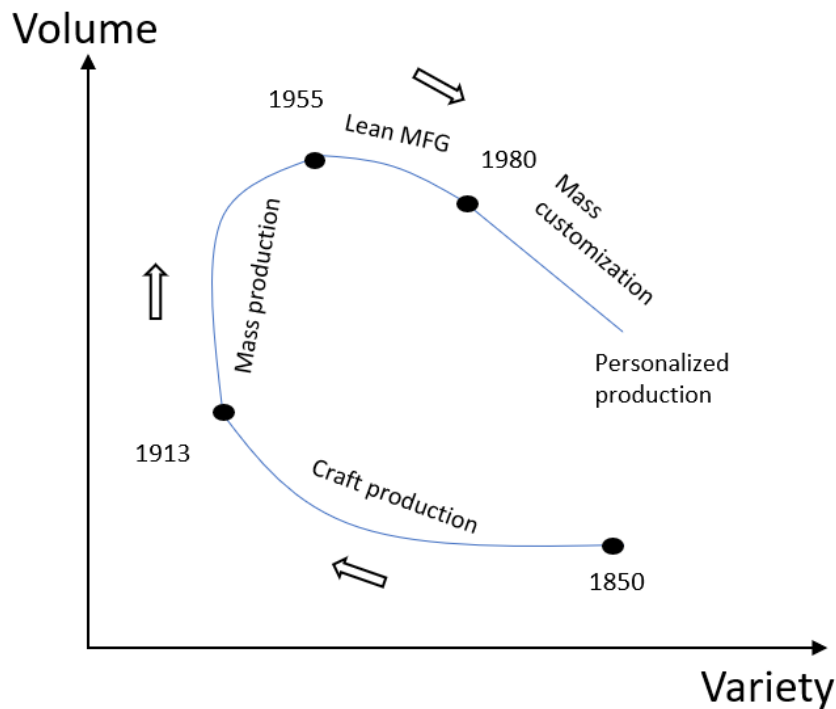


Figure 3. Different manufacturing paradigms (Hu 2013, 4.)

Markets today are growingly customer oriented, and companies have had to change their operations towards mass customization to stay compatible. Mass customization gives customers the option to customize the product to suit their need while the manufacturer is keeping the mass-production efficiency. This requires thorough knowledge of the markets from the manufacturer since the product variety needs to be formalized to fit customer domain. A common way to manage product variety is using configuration software. (Giovannini, Aubry, Panetto, El Haouzi 2013, 10.) Accordingly, two core principles of MC are product ranges that are built modular and utilization of configuration systems to support the tasks related to specification of the customized products (Hvam, Mortensen and Riis 2008, 17.)

Configuration software can identify the product variant from the values entered by the user, and it manages the available product configurations with rules set by engineers. These rules will compose the whole model which is often referred to as product line, product family or configurable product model. (Giovannini, Aubry, Panetto, El Haouzi 2013, 10.) In this study, the product family is used to describe this model.

Companies using mass customization methods need to solve the best possible trade-off between cost and customization attempting to provide individualized products using mass production processes (Duray 2011, 35.)

The fact that manufacturing companies are using customer individualization and variety as competitive advantage has led to problems with the complexity of processes that is induced by the variety. The complexity is caused by the increased number of product variants and their features, more complex modules, and components, adaptable CAD models and efficient planning tools not being used, and lack in streamlining of processes. (ElMaraghy et al. 2013, 644.)

Increase in customization has led many companies to reduce their production quantities. By adding product variants, the company expects to achieve higher sales and prices due to increased customer value but it isn't always so straight forward. In many cases the costs arising from complexity are evaluated too low and the projects might even end up not profitable. Complexity-induced costs are hard to quantify and therefore complexity and costs of variants need to be systematically managed. (ElMaraghy et al. 2013, 644.) Below in figure 4. the usual cost/price distribution of customized products is shown.

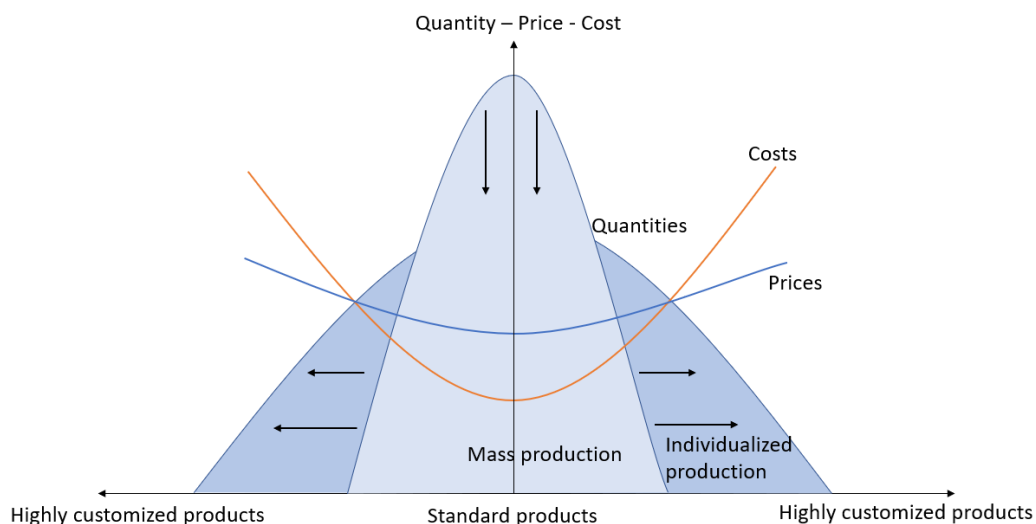


Figure 4. Cost/price distribution of customized products (ElMaraghy et al. 2013, 644.)

Meeting the customers' needs within agreed lead times and budget is the goal of any manufacturer. Important keys for achieving this goal are the right amount of product variety that is built using a common set of modules and product platforms and having a lot of communalities at different levels of product structure. (ElMaraghy et al. 2013, 648.)

The case company is utilizing mass customization principles by having modular product families that are concentrated to different industries and inside the family there are changeable modules that are covering the usual needs of the customers of the specific industry. The majority of the modules need engineering work to meet the requirements of individual customer cases regarding software changes or dimensional adjustments. Hence, the company isn't purely operating in mass customization environment as it is described in literature where all the customer needs could be satisfied with corresponding module variants, but in a more customization environment. And since the customer projects are complex and vary so much in detail it is not profitable for the case company to try to totally move away from customer-specificity by productizing huge amount of module variants to cover all possible cases like companies operating in MC environment would do.

The company has decades of implementation experience and industry best practices in manufacturing, warehousing, tyre manufacturing, paper and board manufacturing, food and beverage and packaging automated logistics solutions. Load handling is one of the key modules for which the company has found solutions through the years of experience and productized load handling options which cover the most common load sizes and types for industries mentioned above. In below picture are shown examples of load handling principles that the company offers.



Figure 5. Load handling principles (Mitsubishi Logisnext Europe, image bank.)

The case company launched first modular AGV design concept in 2007 with intention to move away from customization towards mass customization principles.

2.2 Product architecture for mass customization

Companies worldwide have had to act upon the growing demand for higher product variety from customers. To grow customer value and economic benefits manufacturers have rapidly responded to this need for customization by creating high diversity in their existing products. These new customizable products are not only giving competitive and financial advantages but creating new challenges as operational complexity increases and efficiency in sales, design, production, and distribution decreases. Product family architectures consisting of platforms and modules have been reportedly facilitated these problems. (Bonev, Hvam, Clarkson, Maier 2015, 58.)

To gain the financial advantage of mass customization the products need to have some common modules and design. This means that modularity is the cornerstone of mass customization since it provides the company with a possibility for higher volumes with decent prizes. (Duray 2011, 36)

Modular product architecture is a design practice where the product structure is consisting of number of modules which can be combined to make the product to fit customers' need according to agreed rules and restrictions that set the validity of module combinations. Module is often referred to as standard unit which is combinable, changeable part or component. A module needs to have well-defined functions and pre-defined interfaces to other modules inside the company product family. (Hvam et al. 2011, 596; AlGeddawy, ElMaraghy 2013, 151.)

In the literature there have been identified many kinds of modularity:

1. Bus modularity where every module is connected to common upper module. This is often seen in the computer industry where motherboards act as common modules where different components like graphic cards are fixed.
2. Component sharing modularity where same components can be used in different variants.
3. Component swapping modularity which means that different modules can be combined with one basic module to create multiple product variants.

4. Cut-to-fit modularity where standard patterns can be cut and fit to make for example clothes individual for customer.
5. Selectional modularity which has the highest degree of customization and number of variations, components are connected through unified interfaces. (AlGeddawy, ElMaraghy 2013, 151; Hvam et al. 2011, 596; Hvam, Mortensen and Riis 2008, 31.)

Important things that need to be defined to understand the product modularization are product family and product platforms. The product family can be described as a group of individual products that use similar technology and work in related market applications. (Markworth Johnsen Kristjansdottir, Hvam 2017, 223.) An example of product family could be car like Volkswagen golf which you can get with large number of variants: engine capacity, color, interior, bodywork etc. These variants are made possible by making modules for engine, bodywork, outlook and so forth. (Hvam, Mortensen and Riis 2008, 31.) The Product platform is a common structure of subsystems and interfaces from where similar products can be efficiently produced and developed, meaning a common product architecture for the product family. (Markworth Johnsen Kristjansdottir, Hvam 2017, 223.)

Most important aspect to product architecture is modularity. The highest degree of modularity is considered when every functional requirement can be connected to one module, and the modules are not interacting with each other making it possible change modules without affecting the design of other parts. Modules need to be well defined to make the most out of the modular product architecture. Module is well defined when it has:

- straight relation to customer requirement, ideally one-to-one relationship.
- documented and clear definitions of interfaces connecting the modules.
- product structure which distinct the product functions. (Markworth Johnsen Kristjansdottir, Hvam 2017, 223.)

The level of granularity in modular product family architecture needs to be defined correctly to optimize the product design modularity. Basically, it means the depth in architecture hierarchy of components, modules, and subassemblies. In figure 6 is resembled two different levels of granularity in product architecture. (AlGeddawy, ElMaraghy 2013, 151.)

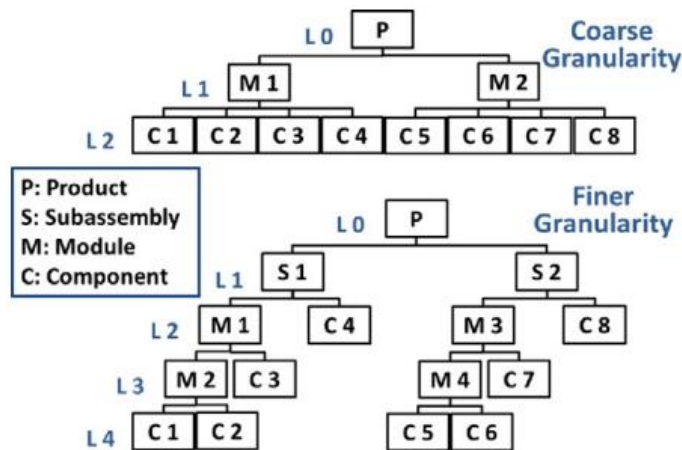


Figure 6. Coarse granularity level and finer granularity level of product architecture (AlGeddawy, ElMaraghy 2013, 151.)

Well-designed modular architecture can produce advantages in many areas during the product life cycle. Modularity will reduce costs and time to process orders and changing the functions or extending the product range is made possible. Modular design also increases the remanufacturing and reusing of components. To achieve these benefits, it all depends on the appropriate identification of common and varying modules and how they can interact. (AlGeddawy, ElMaraghy 2013, 151; Hvam et al. 2011, 596.)

Disadvantages of using a modular approach are that the modules are generally made and therefore might not suit for the specific customer case. For example, the module might not have the correct dimensions or weight to fit like individually designed module would have. This requires figuring out the balance for the requirements and performance, and costs of the whole product family and the suboptimization of each part. (Hvam et al. 2011, 596.)

In ETO companies the modularity and platforms cannot always be considered as physical components because the reuse of physical components between different projects is not always possible, but knowledge and calculations processes can be re-used instead. This needs a bit wider definition for modularity and platforms. For example, module could be defined by a common process step or knowledge. (Markworth Johnsen Kristjansdottir, Hvam 2017, 223-224.)

In the literature there are described many methods to design modules and modular product architectures, but they all include an analysis of customer requirements as a key element. In ETO environment the customization of products is in straight relation to customer

requirements. To make a working product platform and modules ETO company needs to define and understand the solution space and the level of flexibility needed to operate there. One highly used method for this is taking the post-perspective on customizations and looking back at what customizations the company has already done and how they have performed. The idea of this is to then minimize the non-value adding variety and maximize the value-adding variety. From these results modules can be designed without risking compromising the flexibility and solution space while improving the configurability of the products. (Markworth Johnsen Kristjansdottir, Hvam 2017, 224.)

2.2.1 Product architecture of the case company

The case company of this study is utilizing modular design processes. Product structures are created in product data management (PDM) software for managing products throughout their lifecycle. With the structure the quantities and needs for items are controlled, it is a multi-level entity which is constructed from subassemblies. The product structures are being used for three different purposes:

1. Engineering BOM (eBOM) is the generic structure for the product family.
2. Manufacturing BOM (mBOM) is the exact structure produced for manufacturing of the product.
3. After Sales BOM (aBOM) consists of all the spare parts that are possible to sell.

In the case company eBOM is used as base for both mBOM and aBOM. Because of the vast number of variations in products eBOM is constructed as generic product structure. The generic structure covers the whole product family as it consists of modules which can have different variations. In PDM environment the main level of generic structure is accessories assembly under which are the main assemblies and accessories levels. The product family structure consists of MX codes that describe variable structures, X-modules that have at least one variation, and then items that are always needed regardless of the product model. MX structure includes X-items and regular items, and it cannot be acquired since the structure isn't exact. X-item is acting as an identifying item for variable module for example X-item can be called as Mast unit and the variations of it are the individual lifting heights from which one must be chosen for the product. X-items cannot be used alone in the exact product

structure. In figure 7 is resembled the generic product structure approach of the company. (Mitsubishi Logisnext Europe Oy 2017, 14 - 15.)

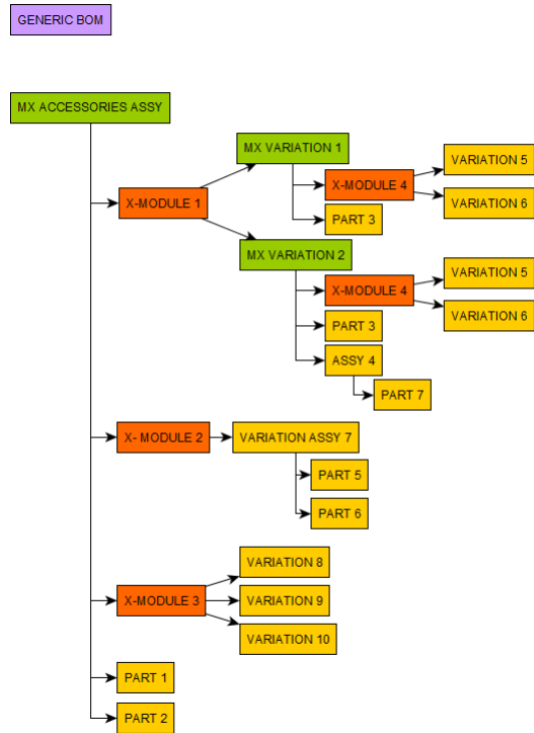


Figure 7. Product structure of the case company (Mitsubishi Logisnext Europe Oy 2017, 15.)

The product is designed to match the desired sales features like lifting capacity, height or loads to be handled. Generic structure needs configurator for defining the variation that satisfies the sales option. Data needed for the configurator are sales options, product variants and the rules between them. The configurator produces the exact structure of the sold product for manufacturing. The principle of configuring the product is that the sales options selected will guide the selection of technical module, the titles of both are characteristic like lifting height to make it clear what is the reason for choosing the variant. For this, rules are needed between the selections, not only what sales options correspond to what technical modules but especially how the selection of one module will restrict the availability of other modules. Product configuration information is managed together with sales features and technical modules in generic data model. (Mitsubishi Logisnext Europe Oy 2017, 15.)

The company's AGV fleet range consists of three product family: pallet movers ATX, automated reach trucks ART, and automated warehouse trucks AWT. AWT product family is the one being configured in this study. The AWT product family consists of different variations of straddle and counterbalance vehicle types. They vary in lifting heights, lifting

capacities, load handling device types and many other features. From these features the vehicle type that best fits the for the customer's case needs to be defined. Limiting factors for choosing the vehicle type can be for example the width of the aisle, the type of cargo to be handled and its weight or shelf height etc.

All the product families are designed modular, and they can be modified according to meet customers' needs. In figure 8. is shown the basic modules of AGV fleet.



Figure 8. Modules of AGV fleet (Mitsubishi Logisnext Europe, image bank.)

In AWT family all the modules can be modified to suit customer specifications. Some of the most common standard variations of AWT vehicles are shown in figure 9.



Figure 9. Standard variations of AWT product family (Mitsubishi Logisnext Europe, image bank.)

2.3 Product configuration

The first case of product configuration can be traced back to late 1970 when a program called R1 was developed by Digital Equipment Corporation. The program was used to configure computer system VAX according to specifications by customers. After this product configuration has attracted the attention and lasting interest of academics and industries, and companies from medium-sized to multinational enterprises have started using configurators to ease their processes. (Zhang 2014, 6381.)

The definition of product configuration can be described as a design process where the product that is configured is built from well-defined component types which can be combined only by a certain way according to constraints set by engineers (Felfernig, Hotz, Bagley, Tiihonen 2014, 3-4.) The framework for configuration modelling is often considered as constraint satisfaction problem (CSP), basically meaning finding out solution that doesn't conflict with the constraints or customer needs (Sylla et al. 2018, 30-31.) This framework is also used in this study.

Key elements of product configuration are summarized by Sylla et al. (2018, 30-31) as follows:

“Hypothesis: a product is considered as a set of components

Given:

- (1) a generic architecture of the product that describes a family of products,
- (2) a fixed set of component groups that are always present in any product,
- (3) a fixed set of component groups that are optional,
- (4) a fixed set of properties that characterize either a component or a product,
- (5) a set of constraints that restrict possible combinations of components and/or property values,
- (6) a set of customer requirements, where a requirement corresponds the selection of a component or a property value.

Objectives: The configuration of a product consists in finding at least one set of components that satisfies all the constraints and the customer requirements.”

Components need to be characterized and represent as set of alternatives so that there are options available for configuration and they can be identified as individual components (Felfernig, Hotz, Bagley, Tiuhonen 2014, 3-4.) For example, when considering a simple crane model, the jib sub-system can have properties like length and stiffness which then have attributes of length: (4 m or 8 m) and stiffness: (low or high). Now the relationship between these attributes must be defined to solve the configuration problem. The relationship is defined by adding constraint which is restricting how they can be combined. In this example the constraint called cc1 is only allowing length (4 m) and stiffness (low) or length (8 m) and stiffness (high) combinations for the jib. (Sylla et al. 2018, 31-32.) In figure 10. is illustrated the configuration model of the crane jib system.

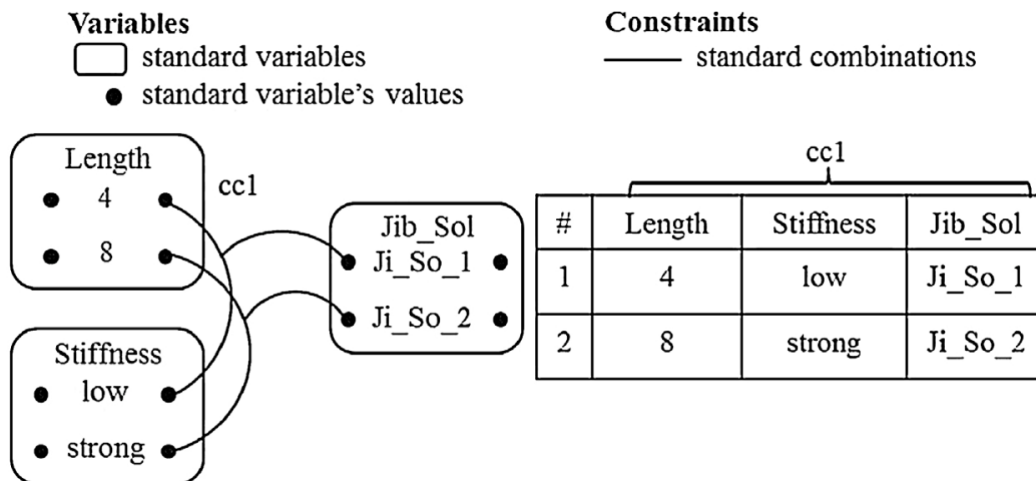


Figure 10. Configuration model of crane jib system (Sylla et al. 2018, 31.)

Configuration models are a great way to store huge number of configurations without the need of listing every possible solution individually into some database. This makes finding the correct solution much easier and maintaining the set of solutions much less time-consuming. (Felfernig, Hotz, Bagley, Tiuhonen 2014, 4.)

2.3.1 Configurable products

What makes the product configurable is the possibility to eliminate all uncertainty from configuration activities basically meaning that the product and its options are clearly defined. Product is configurable when:

- Product family variants that satisfy the needs and functions have been fully defined
- Technical parameters related to the needs and functions are clearly defined.

Company will also need to define what it will offer and create a limited solution space that will satisfy the customer needs to make a product family configurable. And establish a clear link between the commercial and the technical model of the products. (Hvam et al. 2011, 597.)

2.3.2 Different manufacturing approaches

In this chapter the supply chain management models used in manufacturing industry are described to clarify what special features do the different structures have and especially how the company can benefit when moving from these different production structures to configure-to-order (CTO) process. In CTO environment the products are configured to fit customer specific needs and it is often referred to as the most efficient way to use mass customization (Kratochvíl, Carson 2005, 21.)

Assemble-to-order (ATO):

In the assemble-to-order process the variance in products is really limited and components used are standard, usually preassembled to form higher-level components (Kratochvíl, Carson 2005, 23.) Forecasts are heavily guiding the production and procurement of the components only the final assembly is guided by actual customer order. The choices that a customer can make are usually some country specific options like chargers or general technical options and colours. (Kilger Meyr, Stadler 2015, 182.) The options are restricted to defined product lines. This makes the manufacturing and assembly phases very efficient and economical. Competitiveness in the assemble-to-order segment is therefore prices, and support, after-sales and sometimes even delivery times. The process is often used in cheaper cars or PCs. (Kratochvíl, Carson 2005, 23.) ATO environment can be classified in between the Make-to-Stock (MTS) and customer individualized environments (Seiler Greve, Krause 2019, 2973.)

Engineering-to-order (ETO):

Engineering-to-order process is a demanding segment where the products are heavily customized to the customer's specific needs which makes cost and time estimations really complex to keep on track (Seiler Greve, Krause 2019, 2973.) The components can be developed from scratch without any pre-assembly to suit a specific order, making the process a full-scale project. The customization projects are naturally costly and time consuming, and the quality of the final product can suffer from misinterpretations of the requirements during the project. Also, maintenance and upgrades can be hard to implement, and they can turn out to be expensive. (Kratochvíl, Carson 2005, 23-24.)

Of course, the engineering-to-order process has been developed over the years to make it more predictable and reliable. The crucial part of easing the process is sharing the key know-how inside the company. This could be project templates, generative CAD-models, methodology etc. which can lead to major improvements in lead times and costs of the project. Competitiveness is based on correct management of risks, costs, and the project itself and use of fixed price contracts. Examples of products of engineering-to-order environment are usually complex electronics or software. (Kratochvíl, Carson 2005, 24.)

Make-to-order (MTO):

The make-to-order process contains the same special variants as described in ETO, including customer-individualized product development, design, and manufacturing (Seiler Greve, Krause 2019, 2973.) Make-to-stock is still leaning more towards assemble-to-order environment since it is not completely customized case by case. In make-to-order forecasts are driving the procurement and production of components, and final assemblies and distributions are defined according to orders from customers. The demands for the components cannot be forecast as accurately as in more standard environments since they can be customer-individualized or there are simply so many different variants that they cannot be accurately forecasted. (Kilger Meyr, Stadler 2015, 183.) Examples of make-to-order environments are, for example, high end computers. Dell was one of the first companies that utilized MTO for personal computers by allowing the customers to customize their products. (Peeters, van Ooijen 2020, 4663)

Make-to-stock (MTS):

Make-to-stock is basically the opposite of environments which allow customer individualization. The products are manufactured relying on the forecasts and stored until ordered by the customer. (Seiler Greve, Krause 2019, 2973.) The forecasts can be even further included in the distribution process. The products can be distributed in advance to regional distributors to minimize the lead time for customers. Make-to-stock is often used in retail, packaged goods, food, and beverages industries. (Kilger Meyr, Stadler 2015, 182-183.)

Configure-to-order (CTO)

In a configure-to-order environment the components used can be pre-assembled and the specified variation is introduced into the product at final steps of manufacturing. The

variation inside the product is a result of sales discussion with the customer. Computer software is then used to find the correct variant/variants that will suit the customer case. (Kratochvíl, Carson 2005, 24.) In configure-to-order process the customer order decoupling point (CODP) is the same as with assemble-to-order and they are almost similar environments. The completion level of modules is different with them, in configure-to-order the modules are only designed and in assemble-to-order modules are already built beforehand. (Seiler Greve, Krause 2019, 2973.) CTO process produces many advantages including customer satisfaction with shorter lead-times than other customer individual processes, high quality, and predictability of expenses. The process is used by many car and fork-lift manufacturers, computers, and industrial machinery. (Kratochvíl, Carson 2005, 25.)

To give a more illustrative example of how these different processes differ from each other related on the customer order decoupling point figure 11 is presented. CTO has the same CODP as ATO.

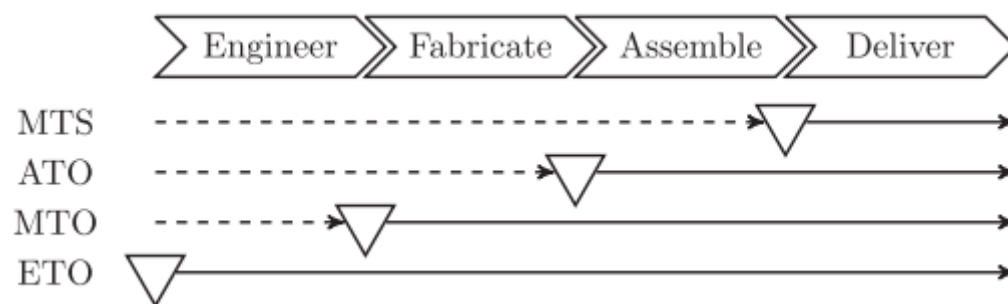


Figure 11. Engineering, fabrication, assembly production and delivery phases of product. (Peeters, van Ooijen 2020, 4661)

2.3.3 Moving to Configure-to-Order strategy

When moving to CTO process the company can achieve many advantages but it all depends on what is the production structure that they start from. For example, the advantages are completely different when comparing moving to configure-to-order from the different extremes of production structures like engineering-to-order where individual customer needs are satisfied with customized products and make-to-stock which is producing bulk products. In the between these two there are assemble-to-order and make-to-order. CTO can be placed somewhere in the middle of ATO and MTO. When moving from engineering-to-order

towards CTO companies will have to limit the variability in products and their solution space while for mass production companies the changes are opposite, configure-to-order will enable more customization in products. (Markworth Johnsen Kristjansdottir, Hvam 2017, 222)

Moving to CTO from ATO/MTO:

Assemble-to-order and make-to-order are so similar processes that they can be seen to achieve same kind of advantages when moving to CTO. Both production structures have a lot of standard components and modules from which the final product is built to satisfy the customer case. Moving to the configure-to-order process can attract new customers since the former not so expensive standard products are now made more customizable with decent prices. This can also lead to extending the product into completely new markets which were not in the domain before. In conclusion the number of options available for customers and their combinations will increase. This can be seen for example in PCs today compared to earlier versions and in many car manufacturers' catalogs when comparing the modern configurators on websites to old paper catalogs. (Kratochvíl, Carson 2005, 27.)

Moving to CTO from ETO:

Mass customization practices have led engineering-to-order companies working somewhere between CTO and ETO. It would be more efficient to work with higher degree of CTO but this isn't always the best solution since it can compromise flexibility of the company to which customers have relied in the past. Companies need to carefully define their solution space and find the best balance between CTO and ETO environments to allow enough flexibility to still offer customer individual solutions. (Markworth Johnsen Kristjansdottir, Hvam 2017, 222)

To make configurability possible companies need to move towards CTO where customization is done by combinations of predefined set of parts and modules. This doesn't mean that the company needs to strictly follow only one of the strategies, it can use a mixture of both. Some of the products can be customized using CTO, others by ETO, and some with mix of both. For example, the product could be built from predefined components and from components that are designed for specific customer case. However, it needs to be stated that when moving towards configure-to-order the solution space always becomes more limited because of the standardization of parts and modules. Level of standardization is important

to balance, reusing the components as much as possible without compromising the flexibility. (Markworth Johnsen Kristjansdottir, Hvam 2017, 223)

Moving towards CTO and increasing modularization in the products company is achieving many benefits. The former complex and expensive products can now be offered with an improved price/performance ratio, higher quality, and better time of delivery. Also, the quotations can be made more consistent, and they are based on facts. By introducing configure-to-order methods ETO companies can also open to new higher volume segments, potential new markets in sub-systems, and a lot of risks are decreased in quoting. The trend of changing from engineering-to-order to configure-to-order can be seen in many industries like transportation and power engineering, construction, and software. (Kratochvíl, Carson 2005, 27.)

Engineering-to-order projects are commonly known to consume loads of engineering resources and lack repeatability, which is needed if the company desires to increase productivity. To have a competitive advantage and success in business the product requirements and information are crucial factors. Requirements hardly stay the same as customers change their minds, new safety standards or constraints could be added by authorities, markets might change, and sometimes the project itself runs into difficulties which lead to revising the initial plan. There are a lot of challenges in reusing information, for example, tracking and tracing the requirements. This is one of the main reasons why companies using ETO need to change their processes towards more systematic customization and CTO to stay competitive in their fields. (Pulkkinen Leino, Papinniemi 2017, 1644)

As a conclusion it can be said that engineering-to-order project companies like the case company of this study need to start making the customizations in a more systematic way. Although a pure CTO environment is not possible to achieve by special equipment manufacturer, as it would eliminate too much from the flexibility that the customers in its field need. An optimal balance between these two environments is the best solution for special equipment manufacturers. (Seiler Greve, Krause 2019, 2979.)

Moving to CTO from MTS:

The reason moving from make-to-stock towards CTO environment is trying to satisfy customer requirements (Biffl Lüder, Gerhard 2017, 5.) Migrating demands the company to

change their existing structures to modular design process to make customization available through configuration. Changing the process from MTS to CTO is not very profitable since the products are usually cheap and highly standardized for the purpose they are used, and therefore customers may not be willing to pay the costs that configurability brings. Customizing the mass products is decreasing the efficiency of order-delivery process by increasing lead-times, risks for errors, and making the sales process more difficult. Although the customization is making it possible for the company to compete more with the options of the product rather than prize if it desires to move its strategy away from mass products. (Tiihonen 1999, 22-23.)

2.3.4 Tacton CPQ configurator

Tacton uses a different kind of approach than regular rule-based configurators. In Tacton the allowed combination of modules and parts is defined with attribute constraints and combination rules. This basically means that in Tacton it is defined how modules can be combined based on their features which separates the data from the logic. Separating the data from the logic reduces the maintenance and errors drastically when new components, parts or modules need to be updated into the system: logic stays the same and rules don't need be changed. In Tacton configurator the number of constraints needed is minimal compared to rule based configurators, for example sudoku can be solved by only applying three constraints. (CPQ Finland Oy 2020; Tacton Systems 2022.)

Tacton recognizes the product structures from PDM software making the product modelling efficient and easy to maintain. One of the most important features of Tacton configurator is its ability to transfer customer needs into correct technical solution and sales bill of material (BOM) allowing the sales personnel and even customers to configure complex products without errors. Tacton also has good user interface modification options which can be visualized, and you can even modify the set of questions based on the user. (Tacton Systems 2022.)

Tacton configurator is developed in TCstudio which is built on XML programming language. The modelling in TCstudio starts by retrieving the product structure from PDM. The product structure is shown in component classes page where component class represents a module and component a variation inside the module for example component class is mast

unit and components are different most variants. Components need features so that they can be identified, and their allowed combinations can be managed. Features can have values based on the domain that they are given. Component classes need to be then realized in the part structure page where constraints are added to the model.

Based on the features and their values the component is controlled with constraints. Constraints are added in part tree, and they apply downward from the upper-level meaning constraints set in the upper level of the tree are applying in the lower level but not vice versa. Constraints define the selection of the correct variant from the module based on value selected by the user.

The features that the user selects are created from the parts attributes and their visualization is controlled in the execution page.

2.4 Current order-delivery process

The current sales configurator is old, and it was originally developed for quoting vehicles that were not standardized. It still suits well for quoting customized vehicles and projects, but a lot has changed since it was launched. The company has moved towards standardizing the vehicles and modules using mass customization principles including modular product family structures to grow the production volumes and to make the business more profitable. Currently the sales configurator does not efficiently support the more standardized approach and it doesn't clearly state restrictions of choices made, what kind of customizations can be done and what would be the feasible limits for them.

2.4.1 Sales configuration

The current order-delivery process starts with the salesperson configuring the quotation for the customers' needs using an independent sales configurator. The options available there are only features of the vehicles and they are not into straight correlation to some existing technical module. From these options the salesperson chooses the ones that most accurately correspond the functionalities that are desired for the vehicle. The contents and descriptions which rise to quote are easy to modify and they can be made to match vehicle functionalities

even in cases where it includes many totally customized modules. The current configurator is great tool for making the quotes for customized vehicles but the downside of it is that the options it provides aren't linked to technical solutions which is causing delays and problems further down the process. This is also forcing the configuration process into two totally independent steps: sales configuration and technical configuration.

The sales configurator is also manually maintained and options there can be outdated, or the newest productized options aren't yet introduced there. The possibility of manually modifying the descriptions and contents that rise to quote gives the sales freedom to quote any kind of customizations of course after discussing with product and sales management if it is possible. This is making it hard to restrict the customizations and making them in a more systematic way which would be much more profitable and efficient, and it is harder to see and control what are the feasible customization to offer.

One problem with the current process of managing the customizations is that there isn't any formal workflow of evaluating the feasibility of the customizations. All these discussions between sales and engineers are now done with emails or calls. Customizations that are realized to delivered projects based on these conversations are not efficiently registered. This lack of tracking the realized customizations is causing delays in the order-delivery process since same type of sales requests could be evaluated several times and due to the communication via unofficial channels the number of concurrent queries from sales can be overwhelming and overburden the project engineering department.

Defining a formal workflow for the evaluation process of the customizations would state a clear work queue for the engineers and more importantly the evaluations would be stored into database. The database would accumulate answers about which solutions can be sought in the future and the technical evaluation work would not always have to be started from the beginning. For example, engineers can immediately see that similar kinds of customization have already been done. The only thing that needs to be checked is the price and availability from the supplier. One of the problems due to insufficient tracking of the customizations is also that not all the profitable and innovative solutions come to common awareness for the sales and product management and remain un productized. With a database consisting of customized solutions for the customers these could be more clearly tracked and presented to the sales and product management.

The current configurator doesn't have clearly defined rules which would for example restrict the invalid combinations of some modules and vehicle types. This requires a lot of expertise from sales personnel and makes the process prone to human errors which could lead to inconsistent quotation.

The sales configurator should be helping the sales personnel to understand the possible solutions that are available for the customer and to guide the sales manager in what can be quoted and what not. In the current configurator there are also flaws in pricing the modules, there isn't any automatic feedback from costs of delivered vehicles and for the customizable options, the prizes are only estimated from the history. Most of the costs are just linked to the main vehicle assembly. To make the pricing of the whole vehicle more precise and repeatable the costs of modules should be better listed and especially what are the costs of customizing the module within the agreed limitations.

2.4.2 Technical configuration

The quotation from the sales configurator is then sent to the customer, and cost management ERP system from where all the costs and bills regarding the project are budgeted and tracked. The sales manager is handing over the information about the case to the project manager who is responsible for carrying out the delivery process of the project. The project manager starts the delivery process with a kickoff meeting where all information needed to design the vehicles is introduced to the engineers. They receive the options listed in quotation and possible customization needs to dimension, sensoring etc. is discussed. After this project engineers start to design the vehicle CAD model. If it is a more complex vehicle there might be some technical aspects that need to be solved. Project engineers also must arrange meetings with subcontractors to give them all the needed information about parameters and possible customizations. The whole vehicle is designed in CAD to match with all the wanted functionalities and an exact product structure is created for every project in PDM. When the design is finished, and the project manager gets approval from the customer that they are satisfied that the design is what agreed in the quotation, engineers can place the order for the factory.

Placing the order starts by making the manufacturing BOM and this is done with a few tools to try to match the exact vehicle structure designed in CAD and PDM. Customer order

numbers are created, and limited numbers of standard options are available in the engineering configurator that is integrated to the factory ERP. Standard options item codes integrated from the engineering configurator appear under the feature codes inside factory ERP. These feature codes are used to manage the picking orders, predict assembly times and many other important things during the manufacturing phase. The missing modules need to be integrated manually from PDM to ERP which is time consuming and prone to errors.

One of the biggest downsides of this manual integration from PDM is that the modules coming from there are all seen as customization inside the factory even though those modules could have been manufactured multiple times in the past. Without standard feature codes the modules cannot be efficiently managed in the factory and a lot of manual work is needed to set up the parameters needed. This is making it harder to schedule the assembly times and preparations for these modules. The new effort to standardize more modules in PDM and CAD models of the vehicles must also be introduced to the operations of the factory. This could mean in the future that the vehicles could be manufactured more in batches of similar products rather than assembling only one vehicle at time. With batch production methods the production efficiency is much higher. The learning effect would increase and set up times would decrease which consume a lot of time in ETO products manufacturing.

The development of adding more modules available in the engineering configurator has not been implemented even though the productization of the modules has been improved a lot because it has been known that this process will be changed after new configurator software has been taken to use.

One challenge of the current order delivery process is the amount of time between order and the start of manufacturing which can be around 5 - 6 months. This is mostly due to extended delivery times of parts and subcontracted modules because of the ongoing geopolitical situation.

The designing of the vehicle takes from 3 days up to 4 weeks depending on the complexity and in some cases the design won't be completely ready after 4 weeks since the subcontractors also need time to prepare their designs of the modules. This is one of the problems that could be tackled by making the customizations in a more systematic way and making the modules to generally more suitable. There have been cases where the

subcontractor has built modules in stock, and they might not even end up used since they don't fit anymore to the vehicles and in some cases the masses of for example load handling devices have changed so much that the vehicle design had to be modified.

Designing the project specific vehicle structure could also be done more efficiently if the sales configurator would be linked to PDM and the sales options would directly print out a list of the technical modules needed to make the vehicle, of course this wouldn't ease the process with customized modules, but it would certainly help the engineering work.

Project manager also creates the project system BOM that includes vehicle structure, and all other components needed to deliver a project like software, layouts, and transportations etc. In future this system BOM could also be integrated in more detail into sales configuration to get rid of the manual work and ease the project managers' workload. In figure 12 is illustrated the whole information system description of the order-delivery process.

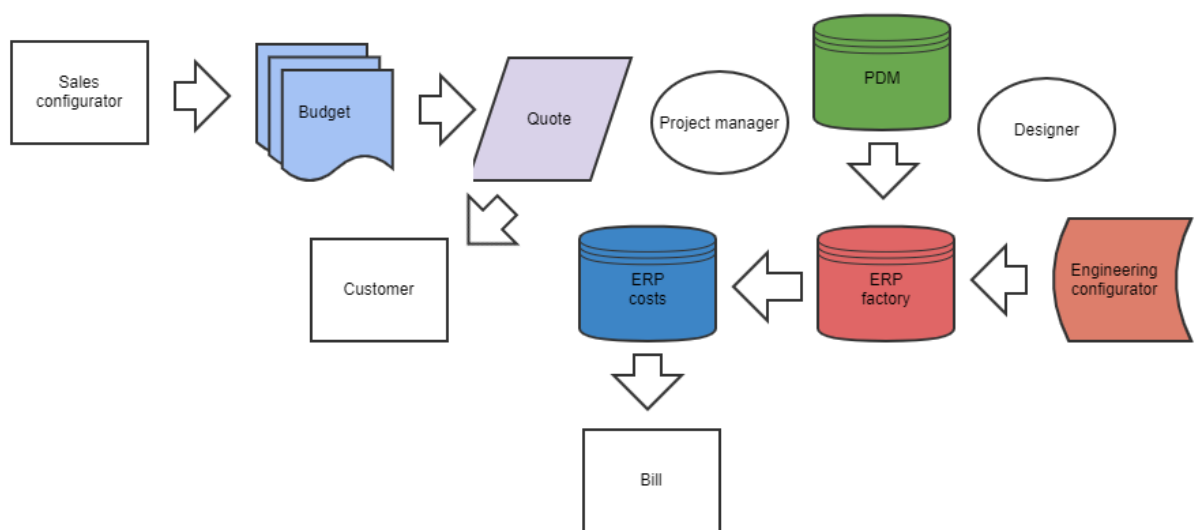


Figure 12. Current order-delivery process information system description.

The fact that sales options don't have currently straight correlation between the technical solutions creates challenges in productization of the product modules since it is not always possible to determine what technical solution would satisfy the sales option. Therefore, a lot of technical modules are not defined properly, and left out from the engineering configurator. This again causes problems inside the factory because all the modules that are integrated straight from PDM to factory ERP look like customized modules since they don't have any feature codes. To increase the manufacturing efficiency and delivery capacity of the vehicles more modules need to be productized and the customizations should be done in a more

systematic way. This is easier said than done but these improvements would increase the profitability of the business.

2.5 New order-delivery process

The new order-delivery process is much more straight forward, and the systems are more closely integrated to each other. The main improvement is the new configurator which makes it possible to improve the efficiency of the process. The new configurator is heavily integrated to PDM and factory ERP and now both the sales and technical configuration are done in the same configurator. This makes it easier to maintain the data and prevent the problem of sales structures and technical structures of the product distancing from each other. The introduction of the new configurator enables a change to a more systematic way of working.

2.5.1 Sales and technical configuration

Products sales and technical structures are now integrated from the PDM to the configurator, meaning that there is now always a current design structure available for technical configuration of the vehicles. The configuration process is still consisting of two steps, sales, and technical configuration this is due to the complex nature of the AWT product family being configured in this study, meaning that the sales options are not always in straight correlation with the technical solution. There must be left enough space for the engineer to figure out the best technical solution for the project.

This new configuration process is a big improvement compared to the previous one since now the sales options are much more closely linked to the technical modules and some of the main technical modules can be locked based on the sales configuration step. Now the choices left for engineers in the technical configuration step are already filtered according to the choices made in sales step. For example, vehicle model, capacity, load handling types and sizes won't have to be configured from the beginning. Technical configuration choices left for the engineers are then filtered by these choices and some of the easily defined modules already locked.

This is minimizing the engineering part after the quotation is sent to customer since the sales options picked by the salesperson have already locked some technical modules linked to them. Engineering will still have to figure out the possible customization needs to the modules but not to translate what modules the sales options might refer to as in the past. Although the engineer still needs to do some of the configuration since not all the technical modules can be defined only by sales options. These improvements will drastically reduce the time consumed by engineers when making mBOM.

Also, the fact that now the data inside the configurator is always matching the latest design structure is making engineers' lives easier. There won't be any more needed to manually integrate standard technical modules which was time consuming. In figure 13. the new configuration process is illustrated.

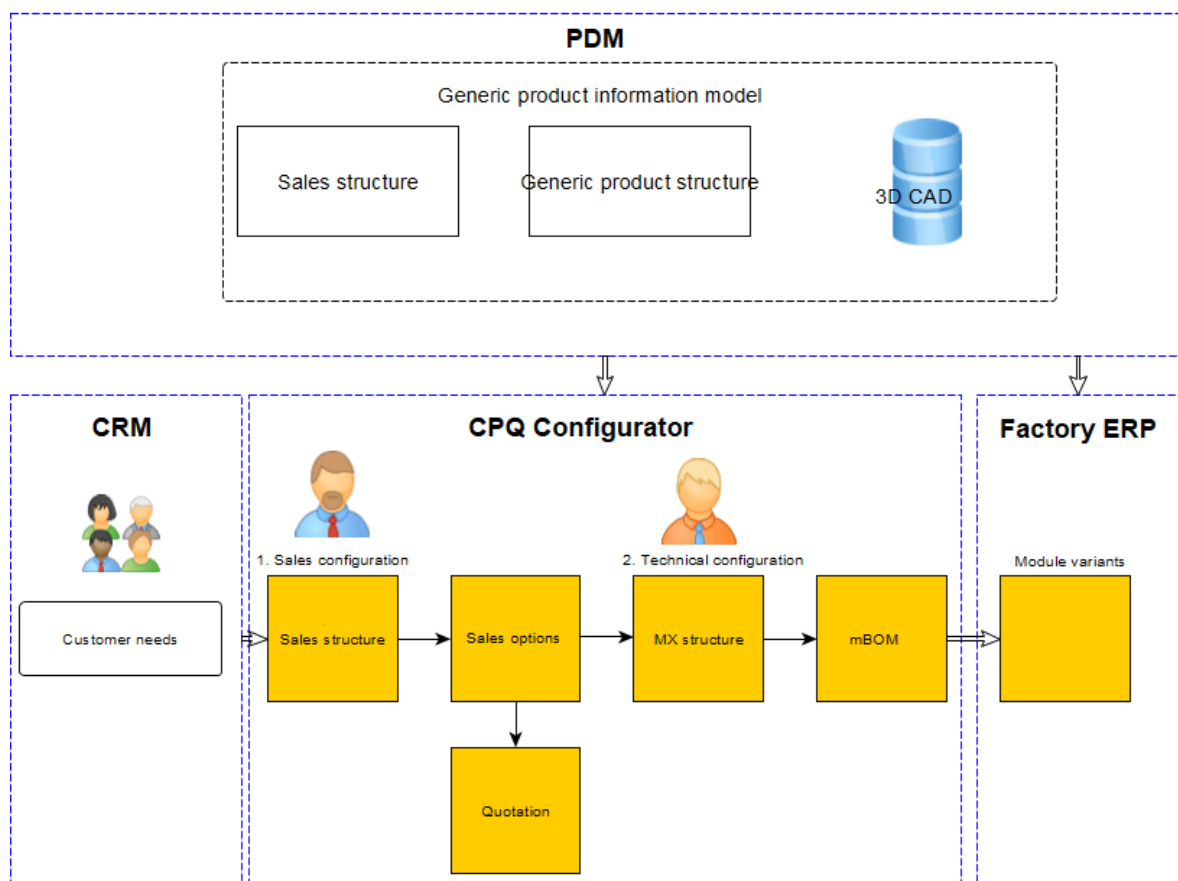


Figure 13. New configuration process for AWT product family.

2.5.2 Managing the customizations

The new configurator is not allowing such freedoms to manually modify the quotation as in the previous configurator which is making it harder to maintain the flexibility of the products that the company needs to be able to satisfy customers' needs. The problem of containing the flexibility of ETO company while moving towards CTO environment is commonly known problem and noted in scientific publications, but there aren't really any clear processes of how this implementation should be done. Therefore, it is studied in this work.

Productization of the modules is also consuming time and resources and needs to be considered carefully, but it is mandatory thing to take care of if the company wants to make the most out of the new configuration system.

The productization work of the modules requires evaluation of the markets and the customers' needs there. Not every possible dimension variation for forks, navigation mast heights or roll clamp diameters makes sense to productize. Instead, some pre-engineered limitations for the dimension variations could be created. This would then guide the salespersons to quote these customizations in a more systematic way and the costs would be more precisely listed and even already agreed with the subcontractor. If the demands of the customer doesn't fit inside these limitations the customization needs more engineering work, and the costs are completely different. Setting these frames under which the customizations make sense to quote could be one effective way for guiding the sales work and to make the order delivery process more efficient.

One way of implementing a more systematic way to evaluate the CSM needs and the impact of the request to further down the process could be categorizing the customizations depending on how demanding they are. For example, ABC categories could be introduced for the customizations. A category CSM request would mean only slight dimensional changes to the existing module, B category would imply some additional components like safety scanners which also require some software work, and C category CSM would be for example, totally customized load handling needing a lot engineering and software work.

When configuring binding quotes these CSM requests would start a workflow, A and B category requests would go straight to engineers if after consultation with solutions management, solution cannot be found using standard options. C category CSM requests are

first carefully evaluated with sales and product management and released to engineering only after decided that the sales case is profitable for the company. After this engineer answers sales what are the total costs of making the customizations requested and quotation can be finalized. All these answers would also be stored into database so that in the future same kind of requests can be searched, and the evaluation work won't have to be started from the scratch.

If the time and money spent on standardizing the CSM dimensions, new component added, or completely new load handling option is seen as more profitable than always requesting it as customization from the supplier it can be added to standard options. And of course, if it is seen applicable to industry standards meaning that it could be sold for multiple projects in the future. This is up to the project engineering department and product management to agree if a new standard option is added to the product family. In figure 14 is illustrated the CSM workflow.

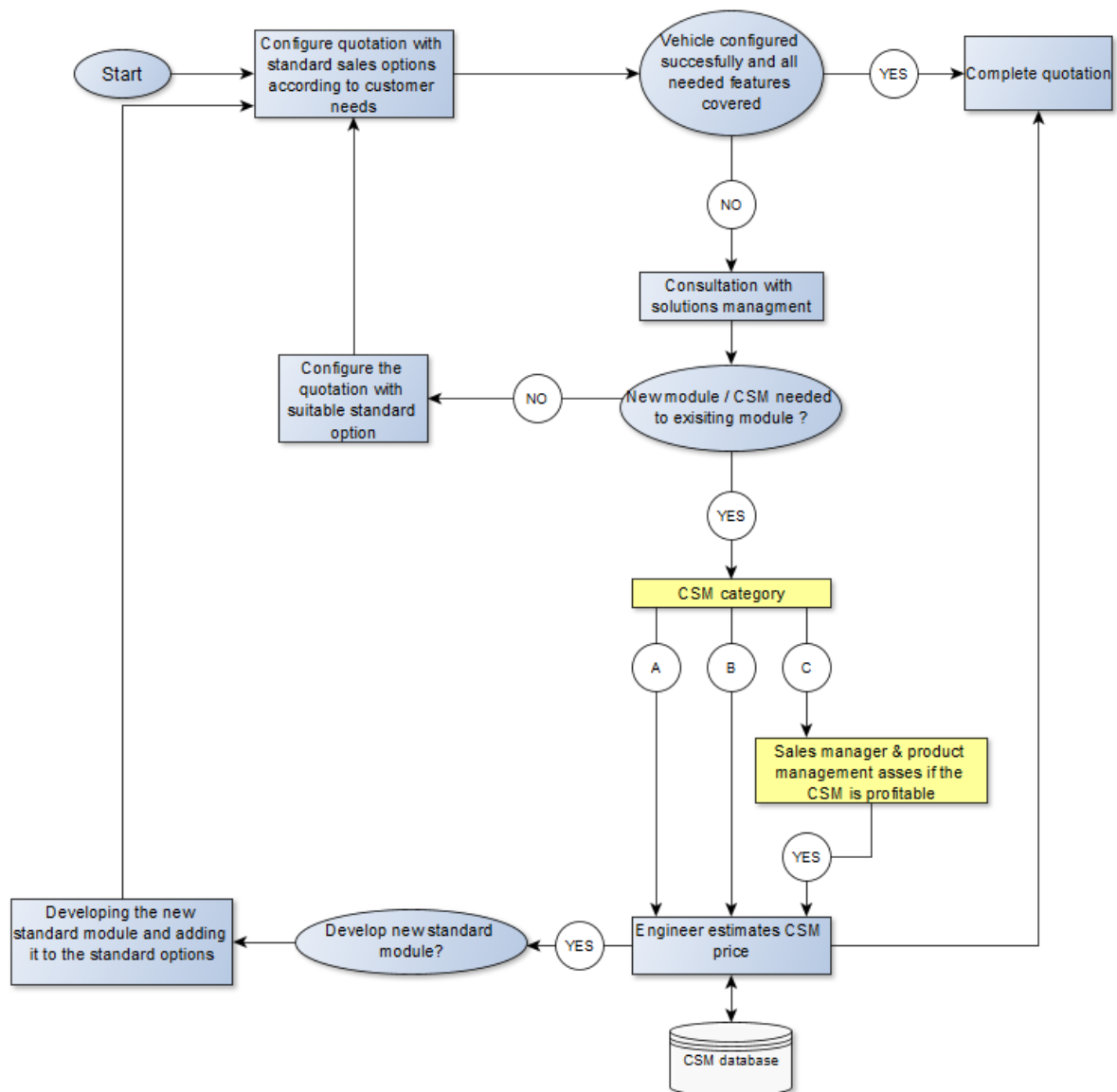


Figure 14. CSM workflow.

Establishing a formal workflow for the CSM requests and categorizing them is a great step towards a more systematic way of managing and tracking the customizations of the vehicles. With this new approach engineers would have clear work queues and the workload that the customizations take is more easily tracked. The heavy C category customizations are considered in more detail if it makes sense to quote. Also, the fact that the customizations are stored into database makes it possible to add feedback into the generic product and sales structure if the sold customization is seen worthwhile to standardize and add it to the product standard options.

2.5.3 Impacts to factory operations

The factory planning and managing the lead time of vehicles will also be improved after a new configurator is deployed since it is forcing to productize the modules that have been previously seen as customized modules inside the factory. It is reducing the number of custom modules and making the products more standardized. All the module variants under standardized X items will now have feature codes, meaning that the consumption can be predicted, and they can be picked as scheduled during the manufacturing phase. Also, the subcontracted modules could now be standardized into more detail which reduces unnecessary work steps during the assembly of the vehicle. In figure 15 the new order-delivery process flow is presented.

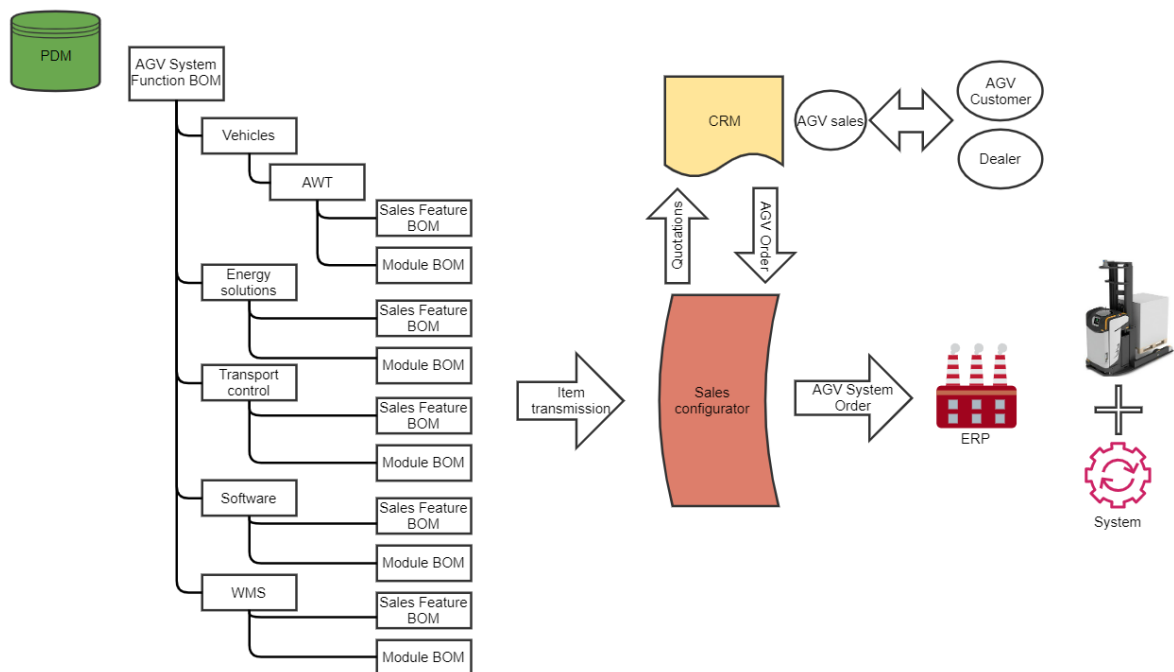


Figure 15. New order-delivery process information system flow.

The reason behind this improvement is made is to increase the ordering capabilities of the AGVs by making them more standardized, guiding the sales and customizations in a more systematic way, and increasing the system integration reducing the manual work and human errors during the process. The change needs to be made to remain competitive player in the global markets.

2.6 TOWS Analysis

Strategy means defining the allocation of resources, long-term goals, and objectives of the company to execute the plans so that the goals can be achieved. Formulating the strategy involves topics like establishing the mission of the company, creating execution plans, listing objectives and deliverables, and agreeing on policy guidelines. (Dandage Mantha, Rane 2019, 1015.) SWOT analysis is a great tool for strategy development, and it is used by companies and research purposes widely. The term SWOT stands for strengths (S), weaknesses (W), opportunities (O), and threats (T). It is used to discover internal factories of the company: strengths and weaknesses, and external factories outside the organization: opportunities and threats. After completing the analysis, the company will acquire knowledge of all factors that can affect the decision making and strategic planning negatively or positively. (Datta 2020, 2)

TOWS matrix was developed based on SWOT analysis as a next step for developing combined strategies and it stands for turning opportunities and weaknesses into strengths. TOWS matrix matches external threats and opportunities with internal weaknesses and strengths. Strategies are then created to minimize the weaknesses and threats as well as maximizing the strengths and opportunities. TOWS matrix forces the managers of the company to analyze the current situation and develop strategies based on organizational objectives and missions. (Datta 2020, 2; Dandage Mantha, Rane 2019, 1015 – 1016.) In figure 16. is visualized the how the TOWS matrix is built.



INTERNAL FACTORS 	STRENGTHS (S)	WEAKNESSES (W)
EXTERNAL FACTORS 	Strengths of organization in the areas of Administration, Production, Finances, Marketing, R&D, Innovation, Entrepreneurship and Engineering	Weaknesses of the organization in the areas of Administration, Production, Finances, Marketing, R&D, Innovation, Entrepreneurship and Engineering
OPPORTUNITIES (O)	SO (Maxi-Maxi) strategies	WO (Mini-Maxi) strategies
The present and future economics conditions, political and social changes, new products or services, and technological changes	Ideal strategies that contemplate the use of the Strengths, in sense of removing advantages of the Opportunities	Strategies of development to overcome the Weaknesses, to explore the Opportunities
THREATS (T)	ST (Maxi-Mini) strategies	WT (Mini-Mini) strategies
Competition, shortage of energetic sources, and Threats presents in the areas described in the quadrant corresponding to the Opportunities	Strategies that concern to the use of the Strength, to face with success the Threats	Strategies that contemplate the formation of Alliances, Agreements of Cooperation or activities clearance sale

Figure 16. TOWS matrix (Dandage Mantha, Rane 2019, 1015.)

Construction of the TOWS matrix starts by identifying the internal weaknesses and strengths first and then external threats and opportunities. After these four types of strategies are formulated:

1. Strength-Opportunity (SO): using the strengths of the company strategies are made to make best of opportunities that area available.
2. Weakness-Opportunity (WO): strategies are formulated to use the opportunities available to overcome the weaknesses of the company.
3. Strength-Threat (ST): strengths of the company are used to overcome the external threats.
4. Weakness-Threat (WT): trying to minimize weaknesses and avoid threats. (Dandage Mantha, Rane 2019, 1016.)

Based on the literature review and interviews held for this study, strategies for implementing the new CPQ software strength-opportunity strategies are formed. The first strategy would be to utilize the tens of years of experience of the project team's personnel on what kind of needs customers have and standardize sales and technical modules based on that. Second

strategy would be to utilize data from ERP and track the manufactured vehicles mBOM's to try to find the configuration level of the vehicles and match the implementation of CPQ to that.

2.7 Value analysis

The crucial part of the product development process is concept selection. The development process usually starts by identifying the problems of the current product. After this company needs to evaluate what is the target market and segment for the product and to summarize the needs of the end users there. Based on these the product development team can come up with criteria on which the choice between created concepts can be made, for example a company that wanted to design outpatient syringe for elderly people summarized the selection criteria as follows:

- Ease of handling
- Ease of use
- Readability of dose settings
- Dose metering accuracy
- Durability
- Ease of manufacturing
- Portability (Ulrich, Eppinger, Yang 2020, 150.)

Now that the criteria for the decision have been defined, a method to choose between the concepts is needed. In some cases, it can be as simple as voting, intuition, letting the customers or clients choose, or different decision matrices. In this study a concept scoring decision matrix is used to choose what modules should be included in generic product structure. It is a more precise matrix and it is suitable if there are only a few concepts under consideration. If the team has dozens of concepts that it needs to evaluate it can use a concept screening matrix to narrow down the concepts. It is a coarser matrix and from there it is hard to score which of concepts would be best, but it is helpful to see which concepts can be taken forward. (Ulrich, Eppinger, Yang 2020, 151-160.)

The concept scoring matrix is used to differentiate the concepts from each other. All the concepts under this decision are now compared with respect to each selection criteria that was defined. The criteria are weighted with relative importance and then the concepts are chosen according to the weighted sum of the ratings. The rating of every concept is evaluated with respect to the criteria. In table 1 is shown a concept scoring matrix for three different concepts A, B and C. (Ulrich, Eppinger, Yang 2020, 160.)

Table 1. Concept scoring matrix. (Ulrich, Eppinger, Yang 2020, 160.)

Selection criteria	A			B		C		
	w	ra	wra	rb	wrb	rc	wrc	
Ease of handling	5 %	3	0,15	3	0,15	4	0,2	
Ease of use	15 %	3	0,45	4	0,6	4	0,6	
Readability of settings	10 %	2	0,2	3	0,3	5	0,5	
Dose metering accuracy	25 %	3	0,75	3	0,75	2	0,5	
Durability	15 %	2	0,3	5	0,75	4	0,6	
Ease of manufacture	20 %	3	0,6	3	0,6	2	0,4	
Portability	10 %	3	0,3	3	0,3	3	0,3	
Total score			2,75		3,45		3,1	
Rank			3		1		2	

2.8 Summary of theory

Companies worldwide have had to change their operations way from mass production to satisfy the increasingly demanding customer needs and to stand out from the competitive markets. Mass customization serves this purpose well by modelling the products as modular product families from which the solutions can then be customized for individual customers. The case company has also designed its products modular for mass customization principles and with individual module variants like masts of different heights or fork lengths etcetera it strives to meet customer's needs. But since the company operates in many demanding industries and produces customized automation solutions for customers it cannot fulfill all possible needs with pre-engineered module variants and some of the modules are needed to be engineered case by case.

With mass customization the product variety also grows exponentially and complicates all related processes. Configurators are a great way to model and store the product families and to develop the order-delivery process. Sales configuration helps salespeople to identify the

product range and to interpret the customer's needs. With product configuration the exact manufacturing BOM's can be identified from modular product families.

By utilizing configuration software to specification processes special equipment manufacturers can develop their operations towards CTO to make their operations more profitable.

In table 2, the comparison between ETO and CTO environments concluded from the literature study of this work is presented.

Table 2. Comparing ETO and CTO effects on order-delivery process.

Engineering-to-Order	Configure-to-Order
Unlimited solution space	Limited solution space
High customer involvement	Low customer involvement
High lead-time from customer order to product delivery	Low lead-time from customer order to product delivery
Low volume	High volume
Uncertain quality	High quality, modules tested and proven in customer cases
Items used only in one project	Common items used in multiple projects
Lot of engineering work after customer order	No engineering needed after customer order
High set up times in manufacturing	Low set up times in manufacturing
Low learning effect	High learning effect
Procurement of components at low economical scale	Procurement of components at high economical scale

As in the table above was highlighted CTO approach brings many benefits for manufacturers compared to ETO. The biggest improvements are decreased lead times and increased efficiency throughout the order-delivery process by increasing the standardization of modules. For many manufacturers CTO would be optimal approach but for special equipment manufacturers like the case company that compete on the market by producing innovative customer specific solutions it is not a possibility to fully adopt CTO approach. It

could limit the solution space too much and case company wouldn't stand out from competition, drastically reduce the selling opportunities.

Instead, balance between ETO and CTO environments where company increases the level of standardization with common modules but keeps the possibility to quote innovative customizations if seen as profitable could be efficient approach for the case company. This kind of hybrid CTO approach means that the solutions are always first tried to be solved only using standard variants that are already engineered. If the customer case cannot be solved using standard variants it needs to be carefully considered with participants involved in implementing the projects that, is it profitable to quote a solution for the case.

With hybrid CTO approach less engineering work between customer order and project delivery is needed. This could also reduce one fundamental problem in ETO companies which is that the customizations are mostly done to fulfill only individual customer cases. When the engineering department is not so focused on making individual customizations, more generalized solutions to industries can possibly be innovated which could provide multiple selling opportunities instead of individual customer cases.

3 Research methods

In this research the optimal level of configuration for the AWT product family is investigated. Models investigated in this study are AWT straddle, counterbalance, and very narrow aisle AGVs. After the correct level of configuration is found a corresponding sales and product configuration implementation to CPQ software is presented.

3.1 Applied research methods

Concept scoring matrix introduced in chapter 2.7 is used for defining the optimal level of configuration. The table compares three different configuration implementations for AWT product family.

First compared implementation is pure CTO approach where only standard module variants are available in the configurator and if the customer case cannot be solved with the existing variants it cannot be quoted. From a configuration point of view this would mean that all the sales options are strictly linked to the existing technical module variant.

Second compared implementation is ETO approach where solution space is not defined strictly and quoting total customizations are allowed. Inside the configurator this would mean that the sales options and descriptions can be manually modified to suit the specific customer case and there won't have to be existing technical solution to the quoted vehicle yet. Engineering would start after the customer order.

Third compared implementation is hybrid CTO, mixture of both CTO and ETO approach. This approach utilizes the benefits of both approaches mentioned above. There would be CTO and ETO modules available in the configurator. The CTO modules would have straight correlation between sales options and technical module variant. ETO modules would also have sales options to create the quotation, and to indicate costs, but the technical module variant selection or design is left for the project engineers.

Statistical analysis of manufactured vehicles is conducted to indicate which modules work well as standardized and where the CSM is often used and needed. Based on these results, improvements to the product's modulation are presented so that it better supports CTO

practices. In addition to reviewing the past customizations the possible future CSM needs that could be needed in industries the company provides solutions is discussed.

3.2 Value analysis

The selection criteria are formed based on four different perspectives: sales, customer, manufacturing, and engineering. From each perspective three criteria to evaluate the suitability of optimal configuration level are formed. Selection criteria are decided together with sales, manufacturing, and design parties.

Sales perspective selection criteria:

- Easy to sell
- Easy to recognize product offering
- Possibility to fulfill customer needs

Customer perspective selection criteria:

- Working solution (without having to modify own operations)
- Price
- Quality of products

Manufacturing perspective selection criteria:

- Standard modules
- Large batch (similar vehicles)
- Manufactured before

Engineering perspective selection criteria:

- Time spent on engineering
- Easy to modify and add features
- More solutions available with standard modules

The weights of the selection criteria are chosen according to the company's goals to develop the efficiency of the order delivery process and increase the order intake of projects. This is shown in the matrix so that the sales (total weight 35 %) and engineering (total weight 25 %) perspective criteria receive the most weight. The three alternatives are scored on a scale of 2 to 8 with intervals of 2. All three implementation possibilities are compared against each other with respect to the selection criteria.

3.3 Statistical analysis

In this study statistical analysis of manufactured AWT vehicles structures is conducted for indicating which modules should be productized into new CPQ software. Based on the historical review and future aspects of company's target markets improvements to the AWT product family modulation are presented so that it would better support CTO practices in the future.

Analysis starts by gathering mBOM data of all manufactured AWT vehicles during 2016-2023. The period is chosen because the product family had midlife update and vehicles manufactured 2016 onwards are all the same generation.

The found structures are filtered by the vehicle models. These structures are then compared to the corresponding vehicle model's generic product structure existing in PDM which includes all modules that are considered as standard solutions.

The comparison is done with data query from factory ERP. The query states that in how many customer orders (CO) the standard module from generic product structure has been included in. This number is then divided by the total amount of the corresponding vehicle models CO numbers during that time to get the percentage of standard solutions of the module in question. General modules that are used in every model are divided by the total amount of AWT CO numbers.

The modules with a low percentage of standard solutions at end products will be reviewed in more detail and the modules that are affected by these changes. Based on these analyses improvements to the products modularization will be suggested to increase the degree of CTO of the AWT product family.

4 Results and analysis

In this chapter the results of the study are presented and analyzed. Firstly, it is stated that what is the optimal operating environment where the company could simultaneously enhance the order-delivery process efficiency without losing the competitive edge of delivering customer tailored projects.

After this the generic product structures modules are reviewed according to manufactured quantities and improvements to modulation are pointed out. Finally, the implementation of new CPQ software is concluded.

4.1 Value analysis

In figure 17 below are shown the results of value analysis.

Selection criteria	w	CTO		ETO		HYBRID CTO	
		ra	w*ra	rb	w*rb	rc	w*rc
Easy to sell	15 %	4	0,6	6	0,9	8	1,2
Easy to recognize product offering	5 %	8	0,4	4	0,2	8	0,4
Possibility to fulfill customer needs	15 %	2	0,3	8	1,2	6	0,9
Working solution	10 %	2	0,2	8	0,8	6	0,6
Price	5 %	8	0,4	4	0,2	6	0,3
Quality of products	5 %	8	0,4	4	0,2	6	0,3
Standard modules	10 %	8	0,8	2	0,2	6	0,6
Large batch	5 %	8	0,4	2	0,1	6	0,3
Manufactured before	5 %	8	0,4	2	0,1	6	0,3
Time spent on engineering	10 %	8	0,8	2	0,2	6	0,6
Easy to modify	10 %	6	0,6	4	0,4	8	0,8
More solutions with standard modules	5 %	6	0,3	2	0,1	8	0,4
Total score			5,6		4,6		6,7
Rank			2		3		1

Figure 17. Results of value analysis.

The most optimal operating environment for the company based on value analysis was hybrid CTO, second best CTO and third ETO. This is consistent result with the company's future goals and as was stated in literature review that special equipment manufacturers cannot fully operate in CTO environment. If the value analysis would have been conducted only for manufacturing and engineering perspectives CTO would have been the best choice

for the company, but the customer and especially sales perspective criteria are strongly in favor of hybrid CTO environment. This is understandable, since by allowing customizations more sales opportunities will open and better adaptation to customer processes will be possible. ETO processes are favored by the possibility to fulfill customer needs and working solution criteria because it offers the biggest possibilities to make customer specific customizations which are tailored to fit for processes at customer premises.

4.2 Statistical analysis

In this chapter the results of statistical analysis of manufactured modules are presented and analyzed. Modules are divided into three different categories: general modules that are used in every model across the AWT product family, straddle modules that are used only in straddle type of vehicles, and to counterbalance modules that are used in counterbalance models. The distributions of manufactured modules are visualized in pie charts, which show the number of pieces and percentages. The percentage of customer specific engineering needed for module being investigated is referred to as CSM in charts.

4.2.1 General modules

In figures 18-21 are illustrated the distributions of manufactured tractor, mast, and load handling units. Tractor unit is one of the main modules of the AGVs. It contains most of the vehicle's electronics, power transmission, and hydraulic modules. The mast unit contains the mast of AGV, and all needed hydraulic components such as pistons, cylinders, hoses, and sensors. Load handling units vary by vehicle model and by loads needed to be handled. In this study manufactured forks, reel forks, clamps, trilateral forks, and telescopic forks are analyzed.

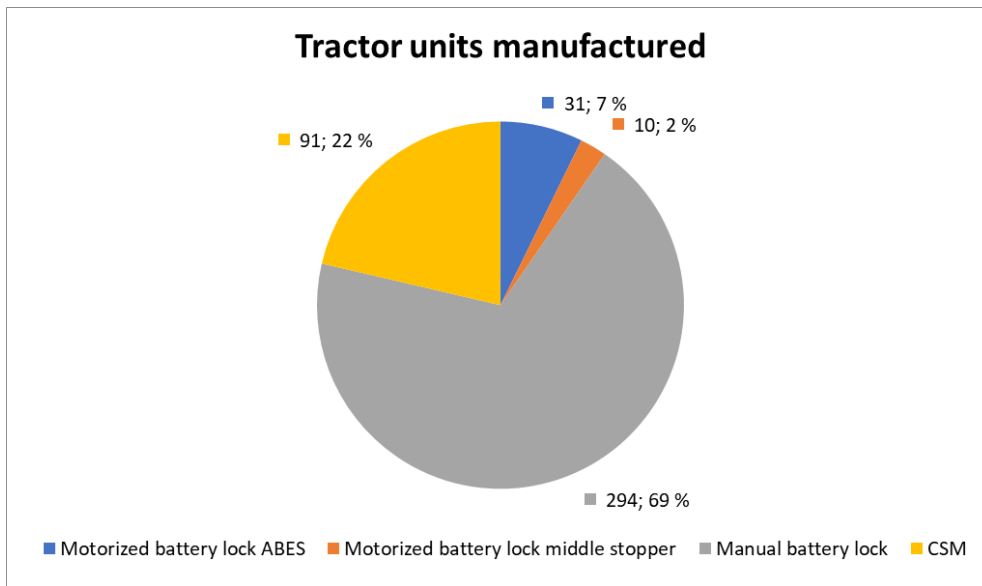


Figure 18. Manufactured tractor units.

From figure 18 it can be seen that tractor modules are standardized well, and about 78 % of all manufactured tractor units are standard. 22 % of tractor units were CSM meaning that some kind of project-specific engineering had to be done so that the customer case could be solved. Manual battery lock tractor unit is clearly the most used module, motorized battery lock ABES module was used only in handful of projects, and motorized battery lock middle stopper module was only used in one project.

Based on the results it can be noted that motorized battery lock middle stopper module is not profitable to keep and maintain as standard module since the solution isn't really used except individual project.

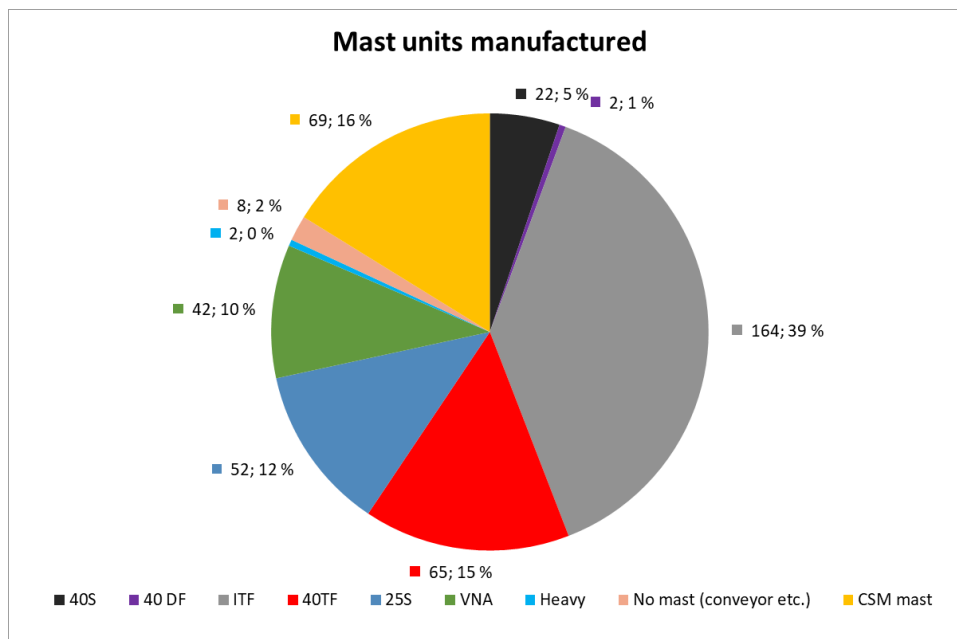


Figure 19. Manufactured mast units.

As seen from figure 19 mast modules work well as standardized, only 16 % of manufactured masts had to be engineered customer specific. What can be noted from the graph is that 40DF and Heavy mast models are hardly used. Especially 40DF mast model is an intermediate model in terms of lifting height and capacity, if shelf height at customer is out of the range from shorter mast models like 40S and 25S the best solution is most probably ITF or 40TF due to the wide range of lifting heights and better capacity they offer. 40DF also has higher structural height which is often a limiting factor in customer premises. Heavy mast model on the other hand is still needed for the product range to be able to solve cases where extreme lifting capacity is required.

Based on these facts it is suggested that 40DF mast model is removed from selection because it doesn't bring any value for the product range and causes unnecessary maintenance work for engineers. Heavy mast model should still be included in the product range as a sales option to get competitive advantage with AWT heavy models to win cases with extreme loads. Although, the technical solution isn't worthwhile to maintain as a standard module due to the low numbers. Instead in the quotation phase it should be noted that it requires engineering and budget the costs accordingly.

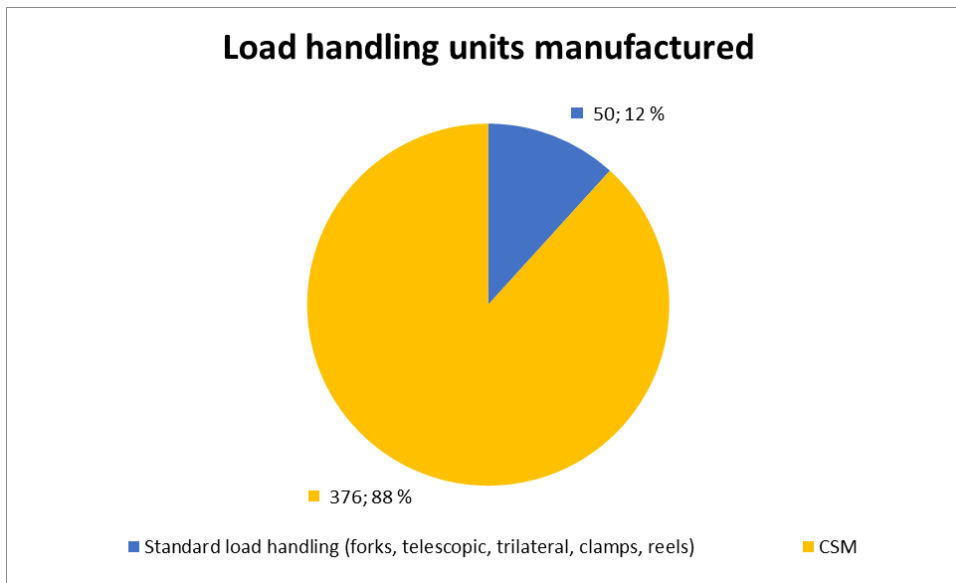


Figure 20: Manufactured load handling units.

As can be seen from graph 20 load handling units are hardly ever standard and usually, they need engineering work to fit the customer's needs. This is explained with huge variety of different load materials, textures, and sizes needed to be handled at customer site. The load handling units like clamps, trilateral heads, and telescopic forks are complex entities that are ordered case by case from subcontractors specialized in them. These special load handling units cannot be fully defined in the sales phase since all load sizes or types may not even be known in the quotation phase which are crucial to define for example the openings of clamps or fork positioner devices. Also, the subcontractors develop and innovate their products meaning that the item numbers and designs change which raises the level of CSM even more.

The high CSM percentage is also explained by the changes made to forks modulation recently. The forks used to be ordered as blanks without any sensors and then tailored on the shop floor to suit the customers case by case. This has been improved a lot since by adding standard sensor package that covers the usual needs and modulating the lengths more accurately making them suit more CTO processes.

It makes no sense to try to standardize technical solutions to all possible load sizes of different industries and therefore these special load handling units need to be identified as ETO modules and only standardize the sales options to carry the costs to quotation. These facts need to be acknowledged and indicated better in the quotation phase so that the need for engineering and the correspondingly increased price are noted.

The paper industry where the case company has long, and successful history is evolving rapidly. Paper production is driven down due to decreased demand and replaced by cardboard production. Regarding load handling units and AGV performances this means increased load weights, reel diameters and many other factors. The case company must be able to respond to changing customer requirements, especially in the industry of its specialty.

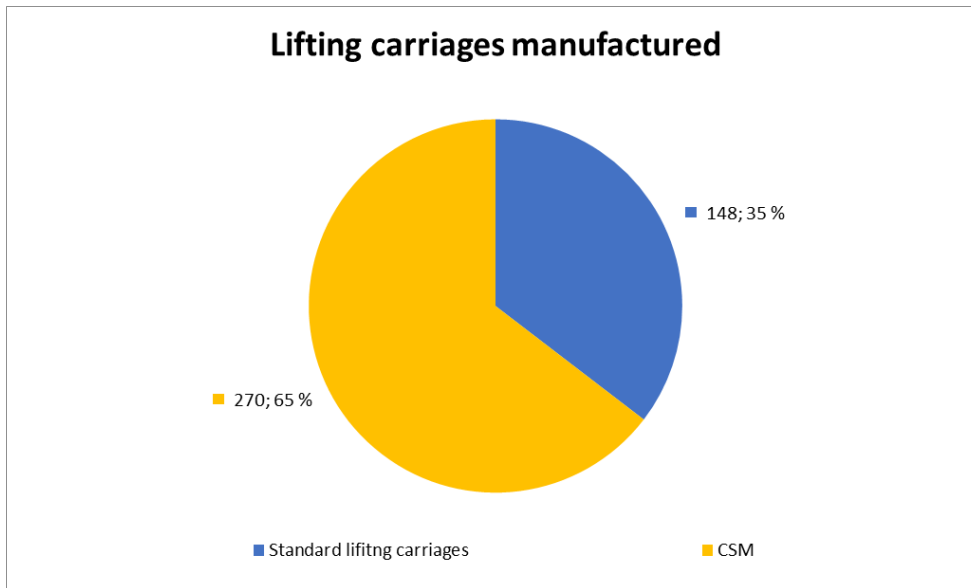


Figure 21. Manufactured lifting carriages.

It is shown in figure 21 that lifting carriages are mostly CSM (65%) and only occasionally standard solution is suitable. This again is due to varying load handling tasks needed at the customer premises, and the level of detail that is needed for the complex carriages with side shift or tilt functions to be fully defined in the quotation phase. The lifting carriages are well standardized for a few AWT models like straddle fork (91% standard) and VNA vehicles (87% standard). Also, the carriages dimensions and structural designs are standardized well but the sensors, fasteners, and wiring need customer specific engineering. They should be evaluated in more detail to see if the design could be changed so that it would work for more of the projects.

There are also a lot more general modules standardized well like hydraulic pumps and blocks, drive wheels and machinery hoods which all have close to 90 % or more standard solutions used in manufactured vehicles. Navigation laser assemblies are general modules that need to be engineered almost case by case especially if extended or telescopic navigation must be used. This is because the navigation laser needs to be adjusted to the correct height

so that the vehicle can navigate at customer premises regardless of the dimensions of racking and loads which makes them tricky modules to standardize. These height adjusted navigation assemblies make no sense to standardize the technical solutions since to almost every case different height is needed, but the prizes and sales options should be standardized for most general ranges to quote them faster and more accurately.

4.2.2 Straddle modules

In figures 22 and 23 are shown the distribution of fork support and safety scanner assemblies of straddle vehicles.

Fork support is a vital module for straddle vehicles. The dimensions of fork support depend on the load sizes and weights to be handled. The company has standardized multiple width-length combinations to generic product structure.

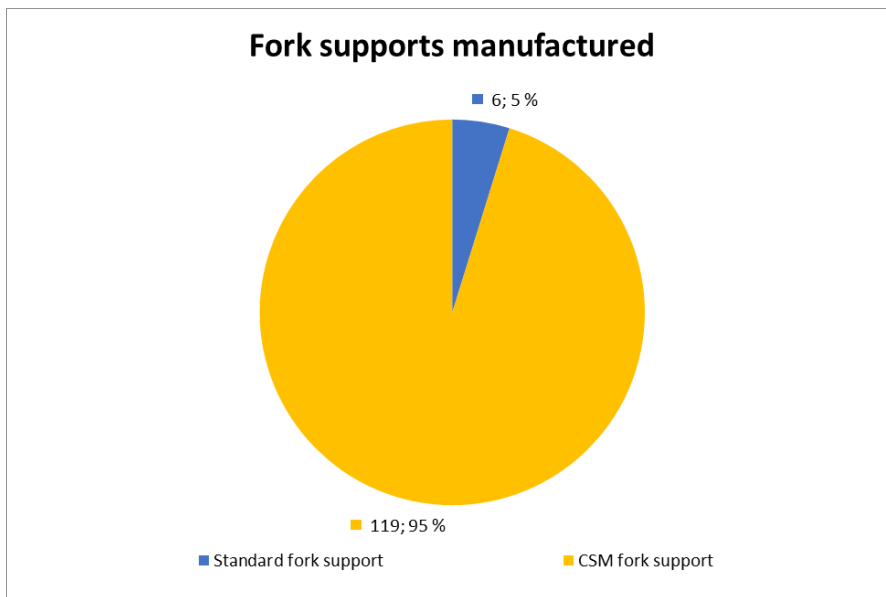


Figure 22. Manufactured fork supports.

From figure 22 it is shown that the existing standard modules of fork support aren't used at all, and 95 % percentage of manufactured fork supports are modified customer specifically. Again, this shows how big variety load handling solutions the company is providing and especially fork supports need to be customized to fit the load handling task. Considering improvements to fork support modules, the work should be started by analyzing the CSM solutions to find any commonalities of width-length combinations which could be

standardized. The customization of fork supports is also affecting other modules like safety edges which must be modified for almost every project individually.

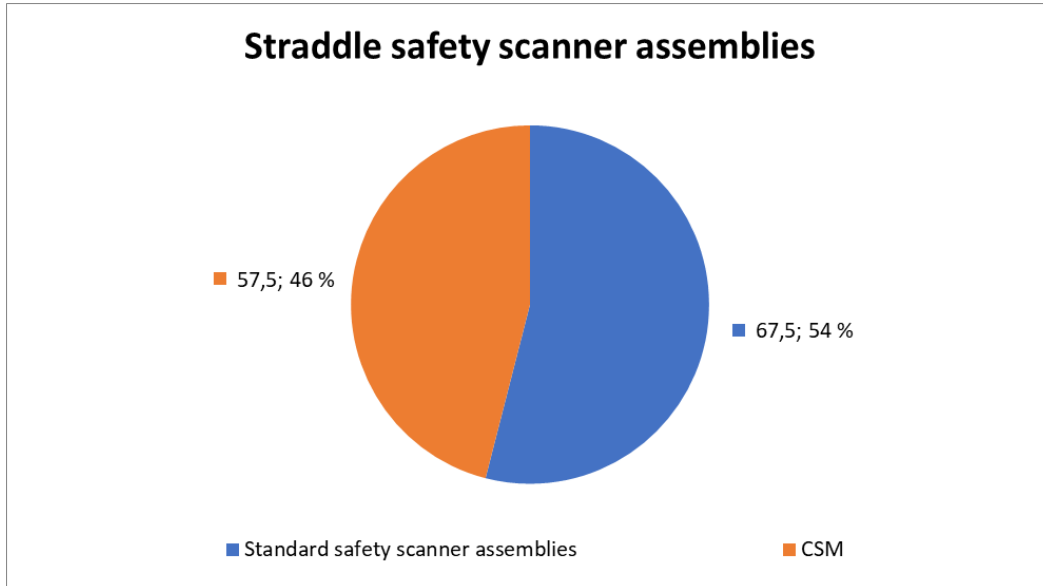


Figure 23. Manufactured straddle vehicle safety scanner assemblies.

As seen from figure 23 straddle vehicle safety scanner assemblies are standardized rather well compared to fork support or safety edge modules, only 46 % CSM assemblies. Modifications are needed due to special fork support, so improving fork supports modularization the CSM percentage of safety scanner assemblies would also be decreased.

4.2.3 Counterbalance modules

In figures 24 and 25 are shown the distribution of chassis and safety scanner assemblies of counterbalance vehicles.

Counterbalance chassis is an important module that ensures vehicles performance and lifting capacity. The company has standardized multiple modules that vary in lengths of chassis and width of the wheelbase.

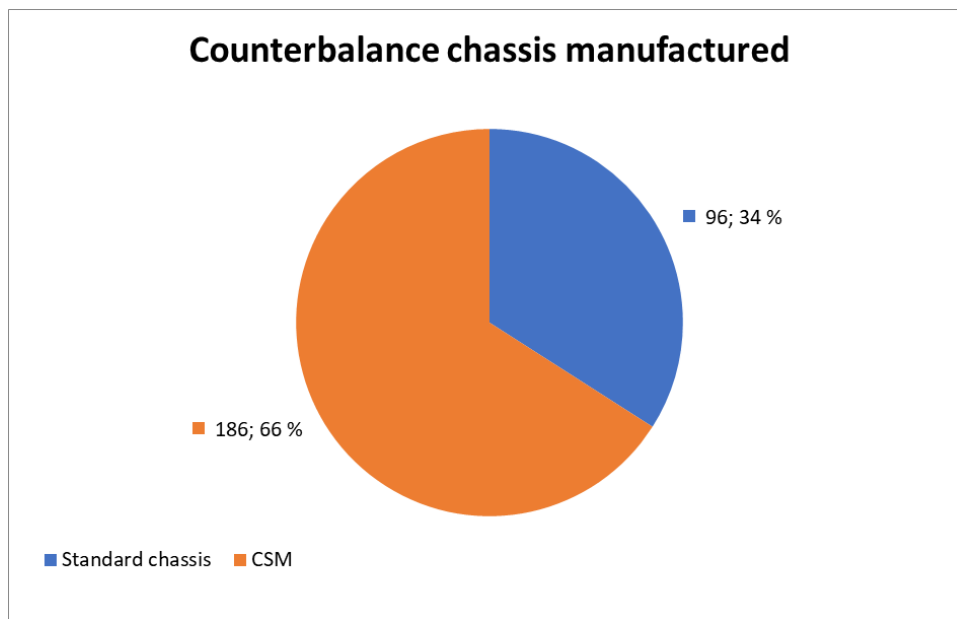


Figure 24. Manufactured counterbalance chassis.

As seen from graph 24, counterbalance chassis usually needed to be modified for achieving the wanted performance of the vehicle. Even though the main assemblies of chassis aren't used in majority of the cases, the different lengths of chassis are standardized well. In about 92 % of the customer cases the welded metal structures for chassis are standard length. Modifications are needed in wheelbase subassembly widths and attachments of safety edges since the safety edges need to be at the same level as the width of the load. The changes of wheelbase width aren't affecting the standardized welded structure of chassis which are purchased from suppliers. Again, this is a module which is hard to standardize, since vehicle outer dimensions are always wanted to keep as small as possible to fit the customer premises. The modifications needed are quite straightforward and they need to be acknowledged when ordering these vehicle types.

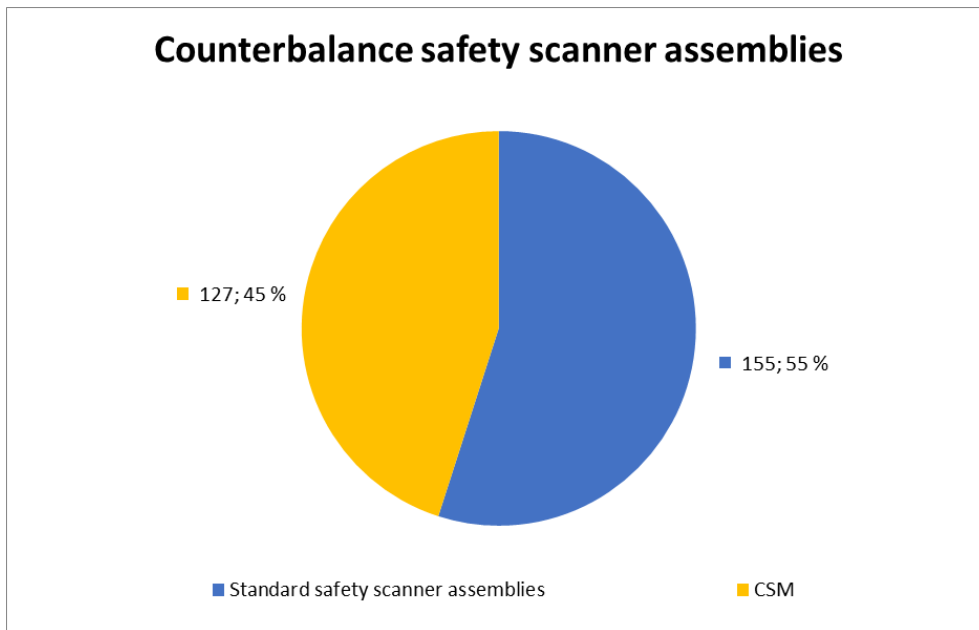


Figure 25. Manufactured counterbalance safety scanner assemblies.

The safety scanner assemblies are often affected by the changes made to chassis module which indicates as relatively high 45 % of CSM. The scanner locations are needed to adjust when loads handled are not so standard but by improving the standardization of chassis module safety scanner modules would also be standardized better.

The CSM solutions engineered for different projects should be carefully investigated to find out if there are any commonalities between them which could be modified to already existing module to make it more general solution or even productize new module if seen profitable.

4.3 AWT product family configuration

The generic product MX structures which contain the standard technical solutions of product families and corresponding sales structures are stored in PDM system. From the PDM to CPQ configurator is built integration which allows to keep the data up to date inside the configurator and to prevent any human errors. In figure 26 the process of building the configurator model is presented.

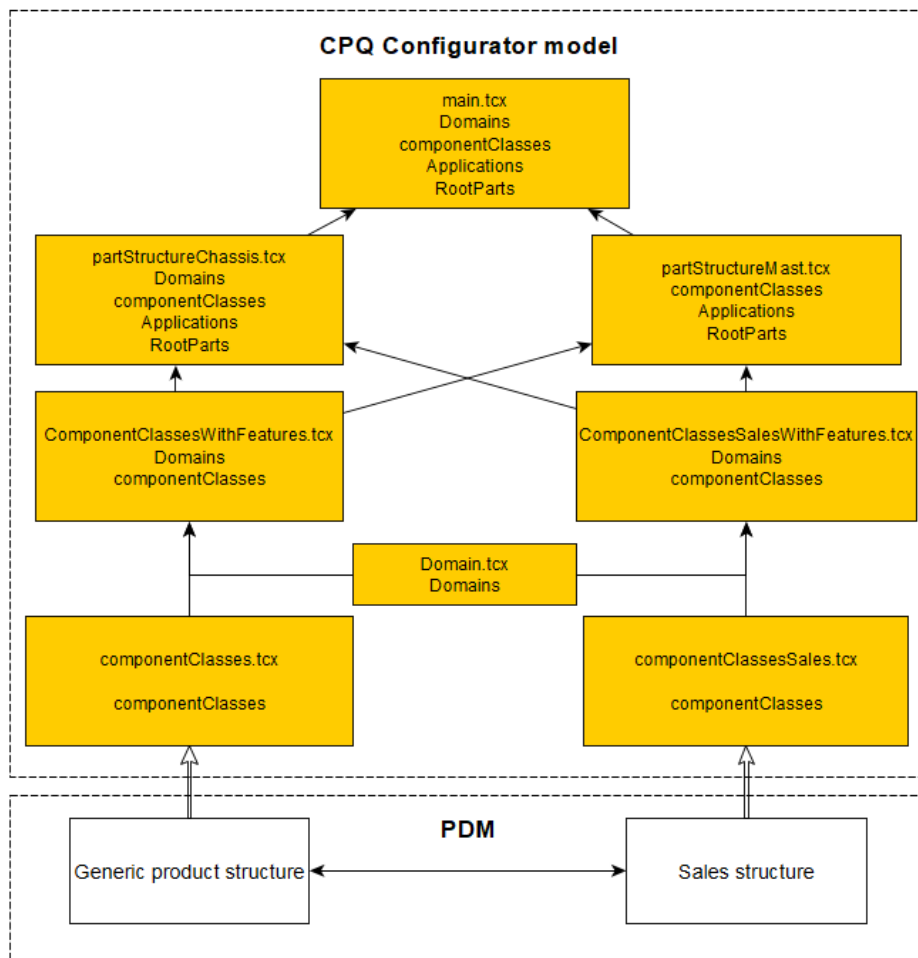


Figure 26. Building the CPQ configurator model.

Sales structure and MX structure are integrated from PDM into separate files called “componentClasses” from which the data is forwarded for processing. The data integrated to componentClasses files is only main level item numbers of technical module variants and sales options, and their descriptions. In the configurator component classes refer to technical modules and sales features and they are storing the individual components: item numbers of module variants and sales options that will be configured.

The data from componentClasses is then included to componentClassesWithFeatures where features and domains are introduced for the components so that they can be identified from each other. Features can have integer, boolean or domain values. Feature presents the properties of a component and which choices it is compatible with. For example, to vehicle main assembly component class is introduced a feature named awtModel and it can have values from awtModelDomain to which all AWT model names are stored.

In partStructure files the constraints to configure the individual components and application to user interface is constructed. The partStructure files are divided into mast and chassis models which contain the corresponding technical modules & sales options. Since the configurator logic is based on constraints rather than rules it is easy to build and maintain. The application of the configurator is also built in partStructure files meaning that the selections that users can make, user rights, visualizations etc. are defined. For example, the selection of AWT model from awtModelDomain can be introduced to the user interface. Once the user has selected the wanted model, to configure the correct vehicle main assembly only one constraint is needed which selects the value of awtModel feature to equal in all parts. This means that from the vehicle main assembly component class the software finds only one solution: component which has the value that user had selected.

PartStructure files are then included in one main file which represents the complete configurator model. The main file is then uploaded into browser-based user interface from where the sales personnel and engineers can use it according to given user rights.

The configuration process of AWT product family is divided into two steps: sales configuration and technical configuration. Sales configuration is done by sales personnel to create quotes. The sales configuration step is shown in figure 27 below.

The screenshot displays the 'Product configuration' interface for AWT vehicles. The left sidebar shows 'Budget Modules' and 'Truck Selections'. The main content area is divided into two tabs: 'About' and 'Special Requests'. The 'About' tab is active, showing a 'Bill of Material' table with columns 'Item code' and 'Description'.

Budget Modules

AGV vehicles

AWT Vehicles

Optional accessories only ☒ No ☐ Yes

AWT model

AWT lift capacity

Truck Selections

Truck options

Automatic battery exchange ☒ No ☐ Yes

Language

Outlook decals ☐ Standard, White ☒ Special, Design ☐ Special, Color

Bill of Material

Item code	Description
HDR001	Sales options
SO000757	AWTcf basic vehicle 2500 kg
SO000735	Vehicle automatic battery exchange AWT
SO000731	open lead-acid, 465 Ah/c5 AWT
SO000818	Food grade oil and grease AWT
SO000829	German AWT
SO000721	Front machinery shield special colour AWT
SO000728	Manual control device AWT
SO000734	Automatic charging left AWT
SO000724	Telescopic navigation laser mast, X mm stroke AV
SO000726	Additional rear laser scanner AWT
SO000806	Fork positioner AWT
SO000855	Residual weight sensor AWT

Figure 27. Sales configuration.

Even though it was shown in chapter 4.2. that the generic product structures of vehicles are not serving the project engineering department as in the mindset of mass customization where the vehicles could be customized and ordered by using already engineered module variants. This is still a big improvement on the previous order-delivery process since now the data inside the configurator is up to date and based on the generic product structures. The whole configuration process is also much more straight forward since now there is only one configurator that is integrated to PDM and factory ERP.

5 Conclusions and discussion

In this thesis the sales and product configuration of complex AGV product family was studied. This study sought to find the solution for modelling the product family into new CPQ software while at the same time keeping the needed flexibility of quoting customer-specific solutions and enhancing the efficiency of order-delivery process by developing it more towards CTO processes.

5.1 Comparison and connections with former research

Enabling product configuration to utilize mass customization principles in ETO companies has been discussed extensively in literature. For example, Markworth, Johnsen, Kristjansdottir and Hvam (2017), Pulkkinen, Leino and Papinniemi (2017) and Seiler, Greve and Krause (2019) all came to same conclusion as this study, that special equipment manufacturers need to form their operations towards CTO but adopting fully CTO process would decrease the needed flexibility to serve customers too much, and instead optimal balance between ETO and CTO operations should be found. Hvam, Bonev, Denkena, Schürmeyer and Dengler (2011) concluded that utilizing configuration software in specification process decreases the lead times and strengthens the company's competitiveness long term which was noted in the result of this study as well.

Markworth, Johnsen, Kristjansdottir, Hvam (2017) and Seiler Greve, Krause (2019) both indicated that the best way to develop the ETO products modulation is to map the manufactured products and how they deviate from the standard solutions, so that commonalities of the customizations and development ideas to the current standard modules can be found. Lots of similar kinds of studies have been conducted with the same conclusions of implementing configuration software to develop the efficiency of ETO companies but they lack information on how this configurator implementation should be done. This study on the other hand also considers this and the modelling complex AGV product family into configuration software was studied and results shown. The results of this study were as expected when compared to previous studies.

5.2 Objectivity

This study was conducted to assist the case company's project of implementing a new CPQ software. The proposed solution was made purely to suit the needs and information system capabilities of the case company. Because of this, the study was not so objective, but the principles presented in the results can be used in similar types of companies.

5.3 Reliability and validity

The results are valid for the wishes and needs of the case company, but the results may not be valid for other companies just as they are presented in this study, since for example, ERP, PDM and CPQ software and their interactions will have a lot of differences between companies. However, the implementation principles are valid regardless of the information systems used and their connections.

The mBOM data was gathered directly from the company ERP system and it can be trusted as the data is used to monitor and control the production volumes of the vehicles. There were slight differences between the systems for the vehicle volumes which could affect the results of some modules by a few percent, but this would not have made any real difference to the results or conclusions. Also, the tracked modules' item numbers might have varied in the early phase after the midlife update because old projects can be supplied with additional vehicles and to fit the system they are manufactured as old generation.

5.4 Assessment of the results and sensitivity analysis

The goal of the work was to produce an implementation model for AWT product family CPQ modeling, and it was successfully done. If, for example, the implementation model is compared to an interview conducted in this study about the development of the order-delivery process, most of the needs discussed there were fulfilled. Sales wanted the configurator to function as a tool that tells which options can be offered and with which models, engineers wanted the PDM and generic product structures to serve as main data for the process and manufacturing wise the manual work for CSM item numbers is reducing since now it won't be necessary to manually add standard components to form the mBOMs.

During this work there was no time to test the implementation model, so it cannot be said for sure whether it brings all the benefits that it was intended to achieve.

5.5 Key findings

The problems of ETO companies and why they should start to systematize their operations was brought up in the literature study of this work and same kind of problems were also acknowledged in case company and reacted by implementing changes to more systematical way of managing the order-delivery process with CPQ software. Most of the studies also noted that for special equipment manufacturers like the case company adopting fully CTO environment where products can only be customized by combining different module variants would not be profitable since it would scale down the solution space and possible sales opportunities too much. Instead, optimal balance between ETO and CTO environments should be found. Value analysis of comparing three different implementation strategies for the CPQ software that were scored with respect to the company's goal to develop the order-delivery process towards CTO and grow the order intake of vehicles lead to the same result that was highlighted in the literature, hybrid CTO had the highest score.

The modelling of AWT product family was made into two separate steps to allow quoting customizations outside of the standard module variants solution space. Inside the CPQ user interface this means that in the first step the sales personnel configures the sales options of the vehicle and in the second step the project engineers will define the technical modules in detail and send the order to the factory ERP.

Statistical analysis of this study pointed out that the current generic product structures are not serving the project engineering department as would be optimal. Many modules need to be engineered customer-specifically. This is the biggest obstacle to the development of operations towards hybrid CTO which the company needs to tackle. To improve the generic product structures so that it would serve better CTO operations the company needs to have resources outside the project engineering team and establish systematic feedback from project implementations to generic product model, as was presented in chapter 2.5.2 figure 14, because the project engineering department's purpose is to serve the individual customer's needs and they will always have tight schedules. These factors are preventing the project engineers from trying to solve the needs in a more general approach that could be

utilized in more customer cases. Also, one big threat to the company's success that cannot be efficiently solved with current allocation of resources are the continuous changes in the markets. For example, one of the company's key target segments is the paper industry that is rapidly moving more into cardboard production, which is causing changes to standard dimensions and weights of loads that need to be handled. There must be resources that are only allocated to develop and maintain the generic product models to stay a competitive player in the market and to be able to develop the operations towards CTO.

The new order-delivery process gives the company a real opportunity to move towards a hybrid CTO environment. Implementation of the new CPQ configurator is enhancing the order-delivery process a lot already and makes it possible to efficiently develop the processes towards hybrid CTO. The fact that now the generic product structure and sales structures are maintained and integrated from PDM to the configurator makes it possible to keep the data up to date, for the sales department to quote the latest vehicle options with correct prices and the engineers can order correct technical modules from the factory without so much manual work. Also, now that the sales structure and technical product structures are maintained side by side in PDM they are more heavily linked. The sales options correspond to technical modules and vehicle features, and now it is clearly indicated if a technical solution is missing from the background of the sales option and engineering resources are needed.

Adapting more CTO environment with the resources to develop and maintain the generic product models, the engineers can truly innovate general solutions to the market and develop the generic product model to serve project engineering better, rather than always trying to quickly respond to individual needs that might be realized only once. This would improve the quality of modules since more of them would have already been tested and proven to work with customers and decrease the lead time of order-delivery process corresponding to the growth of project delivery and order intake capabilities. Also, considerably facilitating the procurement and manufacture of modules, the manufacturing could be more batch production reducing the lead times and the procurement of parts could be done in more economically profitable batches.

5.6 Novelty and value of the results

The value of the work for the target company was the creation of a configuration implementation model and to research what benefits it can offer. The novelty value that this study adds to former scientific research is the practical implementation model of information systems and configuration modelling.

5.7 Topics for future research

In future research the CSM implementations should be studied if there are dimensions/solutions that could be productized as standard modules to improve the configuration level of the AWT product family. It should also be studied how the implementation of new CPQ software will affect the lead times of the order-delivery process and does it serve all parties as was said in this study.

6 Summary

This thesis was made for Mitsubishi Logisnext Europe as a part of a larger project related to implementation of Configure-Price-Quote (CPQ) software in the order-delivery processes. The goal of this thesis was to provide a framework of how a complex AGV product family should be modelled into the CPQ software without losing the flexibility to quote customized solutions and to develop the process more towards Configure-to-Order (CTO) principles.

In the literature study of this work mass customization principles were introduced and how they are used in the case company including the problems that increasing variety and customizations of products cause in order-delivery process. The current order-delivery process and its development points were presented based on an interview held internally at the company. After this, the new order-delivery process utilizing CPQ software that is integrated to PDM and ERP systems was introduced and the benefits it can offer were discussed. Different production environments were also studied and benefits of moving towards CTO processes for special equipment manufacturers and utilization of CPQ software in specification processes was analyzed. From the literature study it was found that by implementing the CPQ software the case company can improve its order-delivery process efficiency by changing it more towards CTO principles.

In the next part of the study the optimal level of configuration for AWT product family was presented using value analysis and it was pointed out that hybrid CTO approach would be the most optimal level to improve the efficiency of order-delivery process and to maintain the needed flexibility to quote customer specific customizations. After this the performance of AWT product family generic product structures were analyzed statistically by pointing out the deviations to realized manufacturing BOMs. Based on this it was noted that the current generic product structures have low level of configurability and they aren't serving the project engineering department as would be optimal. Finally, the modelling of AWT product family into the CPQ software was introduced. The configuration process was divided into two different steps: sales and technical configuration. This allows the sales to quote solutions that are missing the technical solutions in quotation phase.

The conclusions of this work were that the new order-delivery process utilizing the new CPQ software gives the company a big opportunity to change the process more towards CTO

practices. This study also pointed out that the biggest key for developing the process is to improve the generic product structures that currently aren't working in the way that would be optimal. Even though the implementation of new CPQ software is already enhancing the order-delivery process a lot by reducing many manual operations and linking the choices made in the sales processes into correct technical solutions and pointing out when a technical solution to a quoted option is missing.

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