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Rationalization of Product Configurator Output

In the Context of the Case Company

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This Thesis was part of Metropolia UAS Industrial Management Master's program. The Thesis topic was selected to solve a real business problem which existed in the case company. One of the selection criteria for the topic was the possibility to implement a functional solution. Hence, the outcome of this thesis considers not only the ideal solution itself, but also the practical preparations for implementation.

The research work of this Thesis was conducted between December 2018 and April 2019. Although the topic of this Thesis is highly context-related, most of the findings are applicable also in general level.

I would like to thank Mark Davies and Hans Ekman from the case company for allowing and supporting me to conduct this Thesis, as well as to join the Master's program alongside work. I believe the findings and outcome of this Thesis were worth it.

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The objective of this study was to rationalize the product structures extracted from the product configurator. Rationalized product structures extracted from the configurator enable easy and understandable comparison of existing products. Well-rationalized product structures are expected to minimize complexity in the company internal operations and provide transparency towards the customers. Eventually, the number of profitable sales is also expected to increase.

This study was conducted in five steps. First, the objective was defined. Second, the current state analysis was performed, which summarized the identified strengths and weaknesses of the current practices related to product structures. Third, literature review and the search for best practice was conducted. This resulted in the conceptual framework as a tool to approach the proposal building. Fourth, an initial proposal was built based on the previous steps and the key stakeholder input. Finally, after validation this proposal was finalized.

The study indicated that the functionality of already existing system tools were applied rather poorly in the case company. With relatively minor modifications in the existing product configurator, significant results may be achieved in terms of transparency and good command of product management.

The resulting proposal, a Configurator output generator, will be implemented to the case company. The initial proposal has already showed the potential which is achievable immediately after the implementation. Improved efficiency, transparency and possibilities to further develop the proposal are expected to differentiate the case company from the competition. Easily configurable and understandable products are also expected to fit most likely to the desired application of the customer.

Keywords	Product configurator, configurable product, product structures, configuration output, order management, eBOM, BOM

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Acronyms

BoM	Bill of Material
CRM	Customer Relationship Management
CFW	Conceptual Framework
CSA	Current State Analysis
CTO	Configure-to-Order
eBoM	Engineering Bill of Material
ERP	Enterprise Resource Planning
FLU	Front Line Unit
MAU	Multi Assembly Unit
mBoM	Manufacturing Bill of Material
OMS	Order Management System
PDM	Product Data Management
R&D	Research and Development
sBoM	Spare Parts Bill of Material
SCT	Sales Configuration Tool

1 Introduction to Configurable Product Structures

In goods manufacturing industry, reliable, healthy and up-to-date product structures are the basis for professional product management. Product structures, or bills of materials (BoMs), are an organized representation of how dependent parts of products fit together and interact. As such, logical and transparent structures are a prerequisite for actions such as managing changes, comparing costs and benchmarking against new development. Furthermore, a configurable product allows pre-defined amount of flexibility in the product structures. For instance, two products might consists of the same number of identical components, yet the final assembly might still be different. Another simple example is a pre-mounting of a universal mounting kit. The same kit may be mounted in several different ways, yet it always consists of identical components.

Moreover, in companies involved in goods manufacturing business, a product configurator is a tool which offers a pre-defined flexibility in selection of product features. Ideally, the customer is able to customize the product to better fit the application or desired features without jeopardizing the benefits of mass production. This production technique is also called as mass-customization. Furthermore, the product configurator is an essential tool to manage the mass-customization, as the available or allowed combinations of items are presented in understandable manner. The product configurator interprets the selected features and calls the required components based on the other selections. Finally, the output of the product configurator is an extracted product structure which initiates the production of the desired product.

For a product manager, creation and maintenance of the product structures is not perhaps the most thrilling task. Yet, it is certainly one of the most essential areas of the product ownership. Well-organized, understandable and reliable BoM structures provide valuable insight to guide both cost engineering as well as the pricing logic and mitigate risks related to supply chains. Furthermore, they are a prerequisite to understand how products may be harmonized and how new common features could be introduced with minimal amount of new development.

1.1 Business Context

The case company of this Thesis is a publicly listed, large Finnish industrial machinery company. The company is specialized in cargo handling solutions and it is operating globally, yet the home markets are located in Europe. This Thesis focuses on a specific business line which develops on-road load handling machines and solutions. The scope of this Thesis is limited to a specific product range, which consist of truck mounted cranes. This business line operates globally, however, the production unit is located in Middle-Europe and most of the home markets are located in Europe.

Within the case company organization, the focus of this Thesis is placed on Product management in an international context. The Product management has an all-encompassing ownership of the products, which requires cross-functional cooperation and strong commitment from early conception all the way to product end-of-life. Product managers set the roadmaps for product development based on customer requirements, monitor the profitability of the products, as well as support and steer other departments for common goals defined in the company strategy. Explicit knowledge related to configurable product structures are hence crucial part of the basic toolbox of a Product manager. Utilizing a software tool to centrally manage and publish product data is called product data management (PDM).

Production unit, or the so-called Multi assembly unit (MAU), specializes in mounting of components. With this approach, all component manufacturing is outsourced to external suppliers. Hence, the location of MAU is not so crucial when global supply chains are utilized. Therefore, the enterprise resource planning (ERP) data requires harmonization or updates from time to time in the changing business environment. For instance, data transfer from other systems is required in case business lines are merged, a new company is acquired or the MAU is relocated. For MAU, successful transfer projects require explicit input data and hence good command of configurable product structures.

1.2 Business Challenge, Objective and Outcome

Presently, some of the configurable product structures extracted from the MAU product configurator contain errors and item connections are not easy to understand. This is due to several MAU relocations and major ERP and PDM data migration projects. Moreover, some part of the data is not completely up to date or it might be corrupted. As a result, this lack of logical and comparable product structures makes comparison of similar product configurations difficult. In addition, good command of the overall product data is challenging. This consecutively leads to the lack of references for new product development and risk of unprofitable sales.

Accordingly, the objective of this thesis is *to rationalize the product structures extracted from the product configurator* within a selected product range. The outcome of this thesis are rationalized product structures extracted from the product configurator within a selected product range.

The resulting proposal is expected to provide business benefits by supporting e.g. coordination of sourcing activities and engineering updates as structures are easily comparable. Moreover, logical and transparent structures would simplify the management of possible variants and configurations, hence decreasing the implementation time of new features or customizations. Furthermore, simpler, transparent and more efficient internal processes would support the management of front-office operations, such as technical sales and handling of spare parts. Also, the outcome of this Thesis is intended to be utilized for further benchmarking against other business lines with similar product offering within the case company.

On top of the numerous internal benefits, there are also external business benefits expected. First, the complexity to compare products is expected to be decreased also from the end customer’s perspective. Second, finding suitable product for the requested application should become easier and more efficient. Finally, time-to-market for new features is expected to slightly decrease in the long term.

1.3 Thesis Outline

This study was conducted to propose rationalized product structures extracted from the product configurator in order to manage a product range in sustainable and logical manner. The input data consisted ERP and PDM system extracts, internal documentation and interviews with the key stakeholders. Best practice from literature formed the conceptual framework, which was applied when the initial Proposal was defined. The Proposal was validated and fine-tuned based on first pilot trials and feedback from the key stakeholders, after which the final Proposal was created.

This thesis has the following structure. Section 1 introduces shortly the topic. Section 2 explains the applied research and data collection methods. Section 3 presents the current state analysis (CSA), after which the key findings are briefly discussed. The key findings consist of identified strengths and weaknesses of the product configuration output. Section 4 conducts a literature review and discusses the best known practices related to the research topic. A conceptual framework (CFW) is a target-oriented synthesis of the found best practice from the literature addressing the objective and the found weaknesses from the CSA. Section 5 introduces an initial Proposal for the case company combining the CSA strengths, ideas from CFW and key stakeholder input. Section 6 validates the initial Proposal draft. After validation, the final Proposal is explained together with recommendations for next steps. Finally, Section 7 summarizes the conclusions of this Thesis.

2 Method and Material

This section describes the research approach and discusses data collection and analysis methods applied in this Thesis. First, the research approach is discussed. Second, research design is introduced. Third, data collection and analysis is discussed. Finally, the plan for Thesis evaluation criteria is presented.

2.1 Research Approach

The general research strategy applied in this Thesis is mainly qualitative. In addition, the research problem is connected to a specific case in business context including many variables which are difficult to identify. Furthermore, the data collection methods rely on field studies including interviews, internal documents and observations. However, also elements of quantitative and numerical analysis is applied when extracted data is analyzed more in detail. To summarize the general research strategy, this study is a mixed research yet it mainly utilizes qualitative methods.

Furthermore, the selected research strategy for this Thesis is *Applied research*. Applied research “is of direct and immediate relevance to managers, addresses issues that they see as important, and is presented in ways that they understand and can act on” (Saunders et al. 2009:8). Therefore, Applied research results in solution to a problem and is focusing on practical applications rather than universal principles as in basic research. In addition, the context of Applied research includes organizations, objectives are negotiated with originator and time scales are often tight. (Saunders et al. 2009:8-9)

Given that, this Thesis fits well to the definition of Applied research as the aim is to find a solution for immediate business problem in a specific business organization. In addition, the expected outcome of this thesis fits well the definition of the type of Applied research, as it aims to result in solution in a specific practical business problem. Moreover, this Thesis is performed in relatively short time, supporting further the selection of its research approach. The timeline for this Thesis was from December 2018 to April 2019.

Applied research consists of elements from various methodologies, such as *Action research, Case studies and Design research*. Action research is “an approach to research that aims both at taking action and creating knowledge or theory about that action”

(Coughlan & Coghlan 2002:220). Furthermore, it is a sequence of events and an approach to problem solving on a cyclic process. Moreover, the actions are made effective by combining the scientific knowledge and practical execution of tasks. In addition, members of the studied system participate actively on the research, which is conducted together with those who experience the investigated issues directly. (Coughlan & Coghlan 2002:222-223). Therefore, Action research aims to research that both answers the research question and fulfils a practical need. (Blichfeld & Andersen 2006:4).

Action research consists of multiple data collection methods including both qualitative and quantitative methods, which in turn provides extent of relevance and the opportunity to achieve the context related internal perspective and ability to influence the practical results, such as a development project for instance. In addition, the conclusion is likely to be more convincing and accurate as the research is based on several different sources of information. (Naslund et al. 2010:335) However, a typical Action research is cyclical process in nature. (Naslund et al. 2010:337, Kananen 2013:42).

When some of the relevant principles of Action research are selected, drawing on Kananen, a research method may be further defined as *Applied Action Research*, or *Design research* (Kananen 2013). In Design research, a typical objective results in solution which works in practice improving the operations of the given organization. (Kananen 2013:45-47). The differences from Design research to Action research are rather insignificant in the context of this Thesis, however, the lack of continuous cyclic process and the emphasis of contagious and practical problem solving differentiates Design research from Action research. Therefore, the research approach which is applied in this Thesis is Design research.

This Thesis fits well the definition of a Design research (Kananen 2013). First, this Thesis deals with an individual case in specific organization and business environment. Second, this Thesis is focusing on a specific context related business challenge benefitting only the concerned stakeholders rather than finding out general improvement actions. Third, the research result is a change to the better considering only the context and phenomenon which was studied. Fourth, the objective of this thesis is well aligned to typical objectives of Design research. Finally, the timeline of the research limits the practical possibilities for multiple iteration rounds, hence this study is not a cyclic process, yet it consists of iterations to improve the preliminary proposal. This concludes the discussion related to research approach. Next, the research design is discussed.

2.2 Research Design

The research design of this Thesis consists of five major steps and three input data sets. The research design is illustrated in Figure 1. Next, each step and input data is briefly explained.

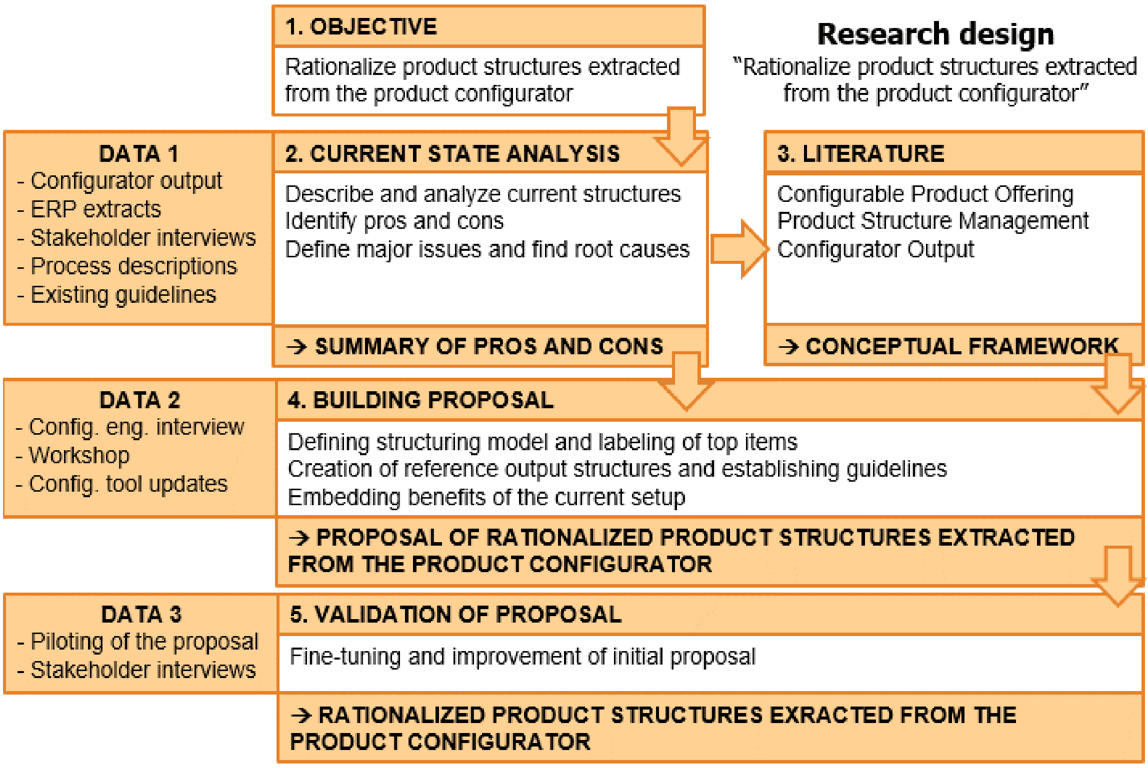

Figure 1. Research design of this Thesis.

As Figure 1 shows, first the objective of this Thesis was defined. The investigated business problem and the business environment is explained, hence setting the context and drawing the boundary conditions for the study.

Second, the CSA was performed in order to analyze and describe the existing practices and methods related to extracting product structures from the product configurator. This analysis is based on the analysis of Data 1, which consists of available internal documentation, stakeholder interviews and data extracts from various tools applied by the case company. The outcome of the current state analysis was a listing of identified strengths and weaknesses of the practices related to the output of the product configurator.

Third, existing solutions and best practice were studied from literature after identification of the existing weaknesses. A conceptual framework was built based on best practice and ideas found from existing publications and related to the topics of configurable product offering, product structure management and configurator output.

Fourth, an initial Proposal to rationalize the product structures extracted from the product configurator was built. The proposal was based on the identified strengths from the CSA, the synthesized CFW and Data 2. Data 2 was collected in interviews with key stakeholders and comparisons to existing practices. Data 2 consisted of key stakeholder feedback and suggestions, as well as highlighted system limitations and opportunities related to desired product configurator tool updates.

Fifth, the Proposal draft was validated by a pilot trial. Feedback was collected and the final adjustments were made accordingly. The Data 3 consisted of round of interviews with the key stakeholders. Lastly, the final validated Proposal was ready for implementation and it was presented to the company stakeholders. Next, data collection and analysis is discussed.

2.3 Data Collection and Analysis

This Thesis draws from a variety of data sources including key stakeholder interviews, database extracts, and relevant internal documentation. The examined data was collected in several data collection steps. An overview of the data collection steps is presented in Table 1.

Table 1. Overview of Data 1-3 collections, content, sources and informants.

	CONTENT	SOURCE	INFORMANT	OUTCOME
DATA 1 CURRENT STATE ANALYSIS	- Analysis of current structures - Identify + and - - Define major issues and find root causes	- ERP extracts - Internal documents - Key stakeholder interviews	- Product manager - Configurator engineer - Production lead engineer - Sourcing manager	- Understanding what is wrong and why - Summary of **strengths and weaknesses**
DATA 2 BUILDING PROPOSAL	- Definition of item structuring model and group assignment of top items - Creation of examples by utilizing reference structures - Embedding benefits of the current setup	- Configurator engineer interview - Workshop - Reference structures - List of active top items	- Product portfolio manager - Product manager - Configurator engineer	- **Initial** proposal of rationalized product structures extracted from the product configurator
DATA 3 VALIDATION AND FEEDBACK	- Improvement ideas to initial proposal	- Main stakeholders 1 to 1 interviews	- Configurator engineer	- **Final** proposal of rationalized product structures extracted from the product configurator

Data collection for this study was performed in three steps, as presented in Table 1. Data 1 was a collection of internal documentation which acted as an input for the current state analysis. The documentation consisted mainly of ERP system extracts together with configured product structure exports from order management system (OMS). In addition, interviews with the key stakeholders were conducted. Details of Data 1 are summarized in Table 2 below.

Table 2. Internal documents used in the current state analysis, Data 1.

	Name or type of data	Content	Description
A	List of all production items	10622 rows	Listing of top items with description and current categorization
B	List of active production items including sourcing information	7461 rows	All active top items in production with sourcing parameters
C	Draft of a product cost analysis template tool	2 diagrams + ca. 400 rows	Example of a product cost breakdown template
D	List of all delivered production items 2015-2018	385358 rows	All 2015-2018 delivered top items listed
E	6 example configurations extracted from product configurator	ca. 360 rows	Existing production configurations extracted for analysis

In this study, the analysis of internal documents made the primary method of data collection and analysis for Data 1. As seen from Table 2, this study analyzed a number of internal documents, consisting mainly of different types of product data extracts.

First, the number of active items and their costs were mapped. For that purpose the listing of all active top items (A) and direct costs for each active item (B) were applied. A simple product cost analysis template tool (C), which provided a simple dashboard overview of the existing top item groups, as well as calculated the direct costs and illustrated them in a form of simple pie diagram. The item costs were included for a visual sanity check in order to compare similar items. In case the cost is significantly lower or higher than other similar items, it is typically due to incorrectly set costs or the structure differs in such way that one top item might equal to a set of top items in another structure.

Second, all delivered top items (D) were investigated. The time window for the deliveries is between first of January 2015 and 31st of December 2018 which is in practice the time the production has been running with the existing system setup. Hence, the ERP extracts are comparable during the examined time window. This listing (D) was included primarily to create a supporting database of delivered top items, yet the second purpose is also to maintain the quantitative information of the volumes for each top item.

In addition, as the input for the order is created in the internal product configuration tool, several different arbitrary configurations were created as a reference. Hence, 6 different product configurations (E) were included as an example to understand how the product structures extracted from the product configuration tool look like after a product is configured. These example configurations were used as a reference for comparisons during the building of Proposal as they define a good overview of the product mix.

Also, this study conducted a series of interviews. The interviews determined the secondary method of data collection. The interviews were conducted as semi-structured conference calls via Google Hangouts due to various site locations in Europe. The aim of the interviews were to identify the key stakeholders related to product configuration process, to understand who are the primary users of the configurator tool and how the tool is utilized. Most of the interviewees were able to explain only very specific tasks and functionality of the system which was utilized during their daily work. Furthermore, it was discovered that only Configurator engineer, which is the person responsible for maintaining configurator tool, together with the Product managers are using the system as intended. No documented instructions existed, hence old unwritten rules were followed and interpreted in various ways.

In total, three formal sessions with the Configurator engineer were hold during the Data 1. In addition, several short ad-hoc calls were conducted, mainly related to details of the practicalities of the configuration process and in order to map the strengths and weaknesses of the existing system. In total, one formal workshop type of meeting was arranged with the key stakeholders, which were the Product managers and Configuration engineer. The relevant findings are summarized in the following sections.

In the next round, Data 2 was collected to prepare initial improvement proposal. Suggestions based on interviews and solutions to found issues were combined. First, Data 2 mainly consisted of detailed discussions with the Configurator engineer as the main focus of the initial Proposal was on the limitations and opportunities of the existing product configuration tool. Second, a workshop-type of meeting was arranged with the Configurator engineer. However, most of the feedback was conducted in an e-mail exchange. Third, a first draft of active top items with new item group assignments was reviewed. This acted as an input for the initial Proposal building. Fourth, first illustrations of the extracted output from product configurator was reviewed.

The final data, Data 3, was collected after the initial Proposal was introduced and piloted for the first time. The key stakeholders at this stage were narrowed down to Product manager and Configurator engineer, as the fine-tuning was mainly related to configurator tool restrictions. Suggestions for improvements were based on the results of first piloting. In addition, refreshed list of top item assignments were reviewed together with the Configurator engineer. In conclusion, the final Proposal was prepared.

All data was analyzed using Content analysis. The selected data analysis approach in this Thesis was qualitative bottom up approach. This was due to the fact that no strict guidelines were available and the investigated data was scattered in internal system tools. The major part of the data analysis was performed during the CSA. This was required to capture the relevant current practices and to summarize the identified strengths and weaknesses of the existing methods related to product configuration output. The CSA is discussed more in detail in Section 3. This concludes the data collection and analysis discussion. Next, the Thesis evaluation criteria are explained.

2.4 Thesis Evaluation Criteria

As discussed in Research Approach, this Thesis applies the Design research (Kananen 2013). The general research strategy is qualitative research with elements from quantitative research. The four criteria of trustworthiness of qualitative according to Shenton (2004) are credibility, transferability, dependability and confirmability. Likewise, the quantitative elements are evaluated by validity and reliability. (Kananen 2013:189, Blaxter et al. 2010:245). However, evaluation of the quantitative elements is neglected.

The credibility assessment of Design research is no different from the general research, however, quantitative and qualitative elements must be assessed with applicable credibility criterion (Kananen 2013:188-193). Next, each criterion is separately introduced including the assessment measure and evaluated applicability in this Thesis.

2.4.1 Credibility

Credibility evaluates the extent to which the findings of the qualitative research make sense. The measures of credibility are adapted from Shenton (2004). Measures of credibility and applicability in this research are collected in Table 3.

Table 3. Measures of credibility and applicability in this research.

Measures of credibility	**Applicability in this research**
Adoption of appropriate, well recognized research methods.	Qualitative research method to be applied in the form of semi-structured interviews.
Development of early familiarity with culture of participating organizations.	The researcher as well as the interviewees are employed by the case company. Hence, all the stakeholders within this study are familiar with the organizational culture of case company.
Random sampling of individuals serving as informants.	Not applied. In contrast, targeted discussions and interviews conducted to ensure the stakeholders provide the best available information.
Triangulation via use of different methods, different types of informants and different sites.	Key stakeholder information combined with relevant internal system extracts and internal documentation.
Tactics to help ensure honesty in informants	Written responses such as e-mails requested. Follow-up discussions after the feedback conducted to confirm the input was as intended.
Iterative questioning in data collection dialogues.	Interviews and workshop type collaboration meetings were in nature flexible and iterative. Each session ended up with summary and conclusion part to confirm the agreed output.
Negative case analysis.	Not applied.

Debriefing sessions between researcher and superiors.	Debriefing sessions with relevant milestones planned to present the progress.
Peer scrutiny of project.	The progress of development will be updated to the key stakeholders frequently. Comments will be required after each relevant milestone.
Use of reflective commentary.	Not applied.
Description of background, qualifications and experience of the researcher	Not applied.
Member checks of data collected and interpretations/theories formed.	The results of the work and synthesis of development will be provided to the key stakeholders during the development, who are requested for comments and suggestions.
Examination of previous research to frame findings	A review of found existing best practice are documented in Section 4.

2.4.2 Transferability

Transferability evaluates the generalizability of the research, which is assured by documenting thoroughly the data collection. Qualitative research does not strive for generalization. The measures of transferability are adapted from Shenton (2004). Measures of transferability and applicability in this research are collected in Table 4.

Table 4. Measures of transferability and applicability in this research.

Measures of transferability	**Applicability in this research**
The number of organizations taking part in the study and where they are based.	Single case company organization, where the study is conducted. Organization is located in Finland and Poland.
Any restrictions in the type of people who contributed data.	The data was collected only from the persons which are working for the organization.
The number of participants involved in the fieldwork.	All relevant key stakeholders will be involved, which are 2 Product managers, Configurator engineer, Sourcing manager and Production engineering manager.
The data collection methods that were employed.	Semi-structured interviews both face to face and conference calls, workshop discussions and written feedback requests.
The number and length of the data collection sessions.	The data collection sessions are arranged as required. However, at least kick-off meetings are planned.
The time period over which the data was collected.	December 2018 – February 2019 (CSA). February 2019 – March 2019 (Data 2). April 2019 (Data 3).

2.4.3 Dependability

Dependability in the qualitative research evaluates the reliability, consistency and accurateness of the study. The dependability can be increased by detailed documentation, so that similar research could be conducted again with similar results. The measures of dependability are adapted from Shenton (2004). Measures of dependability and applicability in this research are collected in Table 5.

Table 5. Measures of dependability and applicability in this research.

Measures of dependability	**Applicability in this research**
The research design and its implementation, describing what was planned and executed on a strategic level.	Research design and its implementation is described in Section 2.2 Research Design.
The operational detail of data gathering, addressing the minutiae of what was done in the field.	The data collection practices are described in Section **Error! Reference source not found. Error! Reference source not found.**.

2.4.4 Confirmability

Confirmability in the qualitative research evaluates the objectivity of the researcher and assures the findings originate only from the informants. Measures of confirmability and applicability in this research are collected in Table 6.

Table 6. Measures of confirmability and applicability in this research.

Measure of confirmability	**Applicability in this research**
Triangulation to reduce the effect of investigator bias.	Data extracts, interviews and feedback sessions are applied to reduce the investigator bias.
Admission of researcher's beliefs and assumptions.	Researcher is part of the case organization, yet the conclusions are reported and documented in transparent manner to minimize beliefs and assumptions of the researcher.
Recognition of shortcomings in study's methods and their potential effects.	The research topic is related to a specific case and context. Hence, the study methods aim to solve a business problem rather than define a general solution.
In-depth methodological description to allow integrity of research results to be scrutinized	Discussed in Section 2.
Use of diagrams to demonstrate audit trail.	Discussed in Section 2. All input data from data collection is stored. Data sources are pointed and the rationale for choices is expressed.

This closes the Section 2, which introduced the methods and material for this Thesis. First, the research approach was introduced. Second, the research design was discussed. Third, data collection and analysis was described. Finally, Thesis evaluation plan was introduced. Next, Section 3 introduces the current state analysis of product configuration output and discusses the findings.

3 Current State Analysis of Product Configuration Output

This section discusses the results from the current analysis (CSA) of product configuration output. The current practices in the case company are presented, including mapping of the relevant processes around the product configurator. First, an overview of the findings is discussed. Second, the relevant practices are introduced related to the product configuration output. Third, the identified weaknesses of the CSA are summarized. Finally, the identified strengths of the CSA are summarized

3.1 Overview of the Current State Analysis Stage

The current state analysis was conducted in five main steps. First, the relevant data was collected. This data was described more in detail in Section 2. The data consisted of extracted product structures from the configurator, listing of active top items as well as ERP data extracts. The ERP extracts consisted of other supporting data such as delivered product configurations from past years, which can be used as a reference to identify which configurations are delivered in reality.

Second, the data was examined in detail, organized and prepared in relevant formats for further analysis. The raw ERP-extracts required further processing in order to capture the relevant data, such as item number, description and information that the item is active in current production. In addition, the material costs were cross-referenced in order to easily confirm that the top items consisted of similar components and to gain an overview of the cost structures. Furthermore, the delivery history from previous four years was connected to the input, in order to identify the high volume items. After all, the high volume items present the most relevant part of the business. Finally, six different sales configurations were created in order to define a baseline for the improvements and understand the format of the extracted product structures. Already the data collection at this point revealed that the input for product configurator seemed to be in order and of good quality, however the product configurator disarrays the product structures.

Third, the prepared data was analyzed. Already the preliminary data analysis revealed part of the strengths and weaknesses of the product configuration process. The engineering BOMs, that are the top items, are of good quality as they pass several audits before they are released and implemented to production. The product data management processes are in place, including engineering change management and lifecycle management. On top item level and component level no mistakes were detected, only some lately introduced items were lacking costing information. The costing information is updated after an item number is introduced, which explains the detected problems. The weaknesses were related to product configurator, which is not completely merged to the product data management. The configuration tool collects the required top items according the selected features, however the descriptions of the top items differ from the descriptions of the engineering data. Moreover, the resulting product structures are listed in arbitrary order, which makes comparison of product structures challenging.

Fourth, feedback was collected from the stakeholders. This step consisted of discussions and interviews with the key stakeholders. The key stakeholders were the Configurator engineer, Product managers, Sourcing manager, Production engineer and Business support managers. It turned out that Production engineering and Sourcing are not utilizing the sales configuration tools as they work mainly on the single item level rather than on complete structures. Hence, the key stakeholders narrowed down to Product managers and the Configurator engineer.

Fifth, the key findings were formulated, including all identified strengths and weaknesses of the current practices related to product configuration process. The identified key strengths were the sound basic design data and design input, commonly utilized product structures, item introduction and management processes are in place, many process steps are automated and common system tools are utilized across the business lines. The identified weaknesses were related to missing guidelines for adding descriptions or parameters to top items, old data is often structured with different logic than today, comparison of similar product structures is difficult, the technical dependencies between top items are not visible, costs of very similar items might differ significantly, several tools are used to fetch the same data and the missing ownership of certain areas of the data.

The current practices around the product configuration output are analyzed below in the sub-sections. First in Section 3.1.1, the relevant stakeholders are identified. This provides transparency and clarity in terms of relevant roles and responsibilities, as well as defines who are either utilizing or defining the critical parts of the existing processes.

Second, Section 3.1.2 analyzes the contents of product structures which are extracted from the product configurator. In addition, the creation process and usage of the product structures are analyzed, which clarifies the requirements for the resulting product structures.

Third, Section 3.1.3 analyzes the process of new item introduction. Product configurations are constantly updated, hence it is of vital importance that new items are included in structured manner. New item introduction explains briefly how items are created and the reasoning why the existing data is incoherent.

Fourth, Section 0 analyzes the product configurator. The product configurator is a tool which collects the valid top items and hence customizes a product to meet the needs of a particular customer.

Finally, Section 3.1.5 analyzes the order management system. OMS is a tool and database where all new, open, invoiced and delivered product orders are stored. Each stored order includes the customer specified features and product structure extracted from the product configurator.

3.1.1 Relevant Stakeholders

The interviews with Sales managers, Sourcing specialists and Product management team revealed that the configurator tool itself is rather poorly utilized.

The Sales units are creating product configurations with old offline price lists, which results in discrepancy between the configurations available for ordering. Moreover, the product configurator is available only for internal Sales units, hence the external Sales units place the orders via their market contacts. In contrast to sales persons, product managers tend to use directly the design data instead of using the configuration tool due to the fact that it is faster and more convenient to focus only on requested feature, or top item, rather than creating a complete product configuration to verify a technical detail.

As a summary of the numerous discussions with the participants involved in the sales configuration process, it turned out that the sales configurator tool is relevant only for the Configurator engineer and Product managers.

In the next section, the product structures are analyzed. The product structures are listings of top items which are utilized by different departments for various purposes. Eventually the output of the product configuration tool is a product structure, hence the product structure utilization is analyzed next.

3.1.2 Overview of the Product Structures Utilized by the Case Company

First of all, the product structures are initially created by the Design department. Hence, the product structures are design driven. Once a top item is created, the created structure is so called engineering bill of material (eBoM). For the sake of efficiency, the eBoM is utilized as such by other departments where only applicable.

Then, after eBoM is created, it will be introduced to the production for manufacturing. It is often practical to divide the created eBoM into sub-parts based on the physical or technical interfaces. This division is performed in order to mount the items according the manufacturing processes. In the manufacturing process the components are assigned to applicable mounting stations. In some cases the production mounters are preparing sub-assemblies before the final assembly, hence the manufacturing bill of material (mBoM) might differ from the eBoM.

Lastly, similar to mBoM, the spare parts bill of material (sBoM) often differs slightly from the original eBoM. The content of an eBoM is for instance a complete mounting kit, whereas only some of the items are typical spare parts. A practical example would be a mounting kit which consists of typical wear and tear parts, say a sliding bearing and two links. The slide pad lifetime is fraction of the expected link lifetime, hence only the bearing is relevant spare part. The relations between the different bills of material are illustrated in Figure 2.

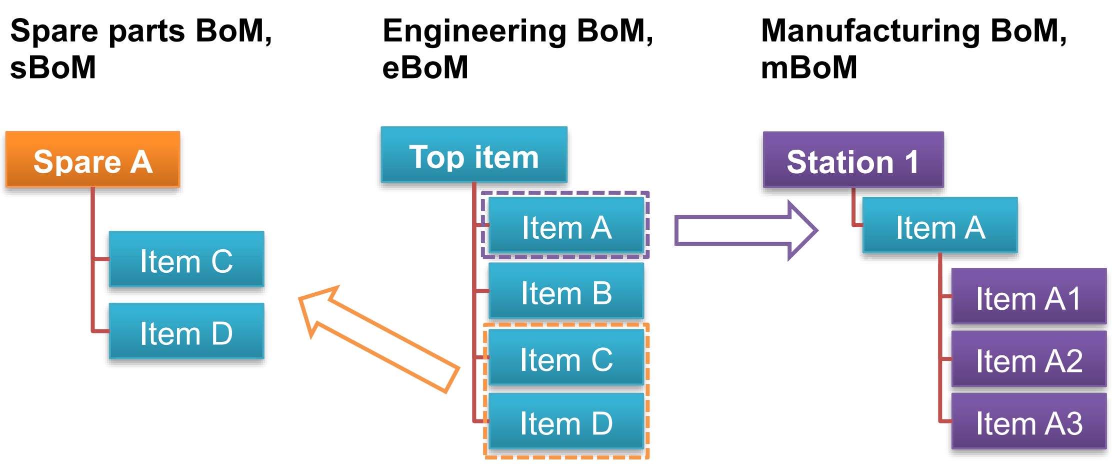

Figure 2. Illustration of eBoM centric approach.

As Figure 2 illustrates, the eBoM acts as a baseline or master BoM which is further reprocessed to create BoMs for other purposes such as sBoM or mBoM. To sum up, the case company is dealing with several types of BOMs which are all based on the eBOM. The benefits of the approach are relatively easy change management as all BOMs follow the updates in eBOM. It is also beneficial to use the same item numbers throughout the organization instead of duplicating them for different purposes. Next, the parameter assignment of product structures is analyzed. The parameters are visible in the extracted product structures from the product configurator output, hence the parameter assignment steps are discussed more in detail.

3.1.3 Parameter Assignment of Structures from Creation to Configurator Output

First of all, each item requires a unique article number and technical documentation describing the content. Typically the content is described with relevant technical documentation, such as a technical drawing. However, as only text type of data is transferred to ERP, the content is described with parameters such as article number and description. Additional parameters such as mass, relevant standards or additional descriptions may be added as well, however there are no strict guidelines in place related to these additional parameters.

Continuing, once the structure is ready to be released and implemented to production, it is exported to ERP system. ERP collects only relevant attributes, which are not always comparable with the already existing database of top items. This is due to the fact that the naming conventions have been changed, databases merged with different business lines and production sites over time.

The top item process flow from creation to extracted configurator output is illustrated in Figure 3. The top item number and content remains unchanged during importing and exporting between systems. However the item description among other parameters might change during the data transfer. This is because of the differences in parameter field length limitations, as well as the parameters which are transferred between different system tools. Due to this phenomenon, the production engineering is only working with article numbers which remain unchanged, as the item description might be misleading or even completely missing.

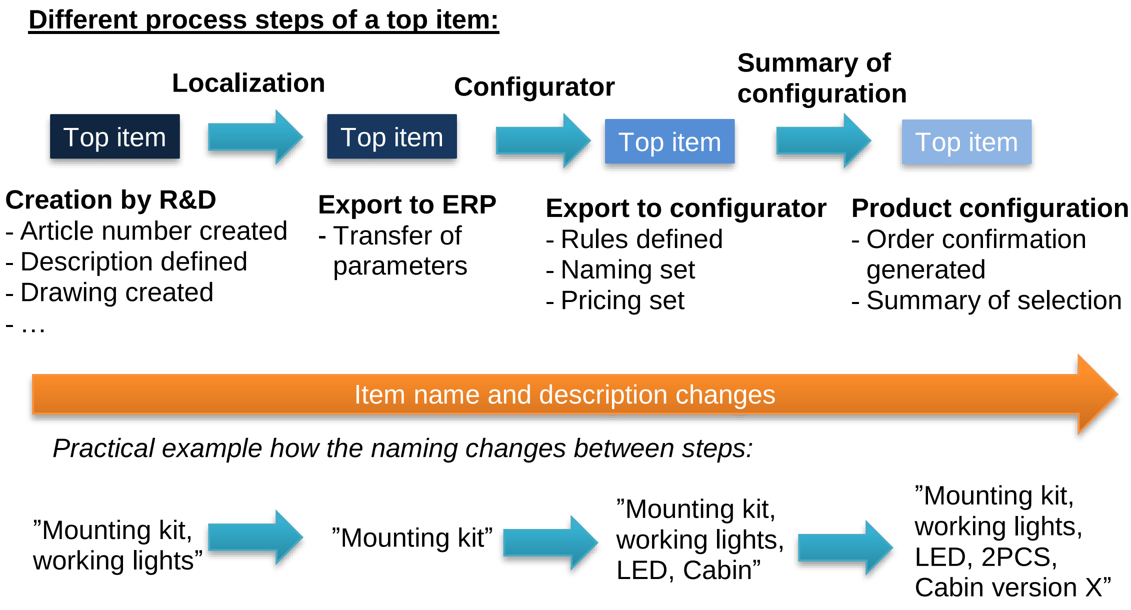

Figure 3. Illustration of a top item process flow from creation to product configurator output.

Furthermore, as Figure 3 shows, a top item is exported between different systems. The first step is called localization. In localization, Research and development (R&D) creates the top item and exports it to ERP. When the top item is localized to ERP, it is successfully implemented to production, and all necessary production parameters such as consumption forecasts, supplier information and item costs are set. Second step is exporting the item to the product configurator. Configuration rules are set together with commercial information such as pricing. After that, the top item may be released in the product configurator. When the top item is released in the configurator, it is visible and available for sales. The third export is the configuration output. Once a configuration is created including the new top item, it is visible in the configuration output.

To sum up, this section analyzed the characteristics of the item export steps which results in alteration or even missing of some of the parameters. The transferred parameters are either not defined in some of the systems, or the number of allowed characters is exceeded and so the parameters are trimmed. This is the reason for the deviation between the initially set description and eventually resulting configurator output. Next, the Order management system (OMS) is analyzed. OMS is a central database where all ordered configurations are eventually stored. In addition, the ordering process is briefly discussed in the next section which clarifies the role of the configurator tool.

3.1.4 Order Management System and Configuration Process of the Case Company

Order management system (OMS) is a database where new, open, invoiced and delivered product configurations are stored. The tool is a combination of a configurator and customer relationship management (CRM), as it is also possible to store the customers' contact data and order history.

The maintenance and definition of the available configurations is on the responsibility of the Product managers, however the practical programming work is performed by the Configurator engineer. The high level layout of the process is illustrated in Figure 4. The standard order process flowchart, which describes the order process more in detailed, is included in Appendix 1.

Furthermore, as Figure 4 shows, the front line unit (FLU) places and order to Order desk or directly to the sales configuration tool (SCT). FLU is for example an internal sales unit, importer or dealer, depending on the sales channel of the market. The SCT requires access to company intranet, hence the two alternative arrangements exist. Once the order is successfully configured and transferred to OMS, the FLU can access the order and follow the progress.

As for the roles and responsibilities, Product manager defines the offered configurations and possible limitations, the Configurator engineer sets the rules in the SCT. In addition, Product manager might need to inform Order desk of non-standard orders which are created manually bypassing the configurator tool. The special orders require often modification of sales or production components, hence the product manager needs access to edit the active orders in OMS. Overview of the information flows is shown in Figure 4.

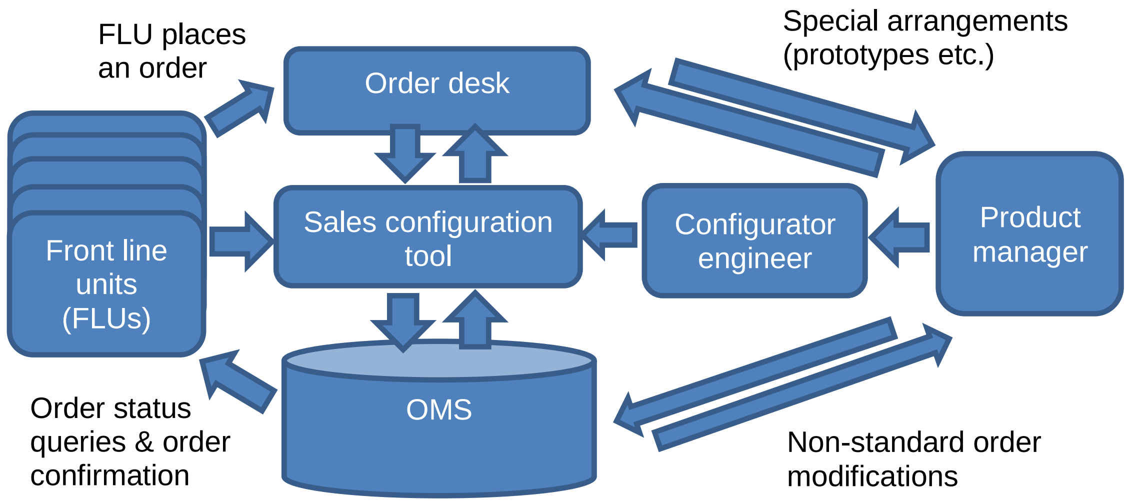

Figure 4. Illustration of the OMS information flow with roles and responsibilities.

As shown in Figure 4, the communication from FLUs is unidirectional as only read access to OMS is allowed. On the contrary, Product manager and in rare cases also Order desk need additional editing access in case modifications are required in original production orders.

Summing up, this section analyzed the information flow related to order process and the relevant stakeholders around the sales configuration tool. In addition, the roles and responsibilities related to the configurator tool were discussed. Next, the product structures extracted from the configurator are analyzed.

3.1.5 Product Structures Extracted from the Product Configurator

The output of the sales configurator tool provides a listing of required top items. In fact, there are two different outputs. One is the listing of top items, the eBoM, and second is collection of sales components which is visible in order confirmation. The sales components are created to simplify the configuration towards the customer. For example, when the product is equipped with working lights, the customer sees a sales component "working lights, LED", whereas the sales component calls top items "switch for lights", "mounting kit for switch", "cabling kit for working lights" and "working lights, LED".

Furthermore, different products require unique connection kits as for example cable lengths differ. Hence numerous very similar variants exist. As the result of analysis in Section 3.1.3, the item descriptions as such are irrelevant for the production as they mainly deal with article numbers. However, for Product management and other internal stakeholders the misleading descriptions complicates the direct comparison of configurations. Figure 5 presents a symbolic illustration of this issue. The item types categorized from A to E could refer to, for instance, hydraulic, electric or mechanical components which are typical items to be compared between product configurations.

Figure 5 illustrates the challenge to compare extracted product structures without further processing due to the following reasons.

Figure 5. Symbolic illustration of current state comparison of two product configurations.

First of all, as Figure 5 illustrates the items are scattered in arbitrary order. In addition, the descriptions are in some cases misleading, and hence the comparison of structures requires manual processing to regroup the items for understandable like-for-like comparison. Sorting of the item order is not possible with the current setup as the naming convention is not the same for all items. In addition, very comprehensive product knowledge is required to identify which items are collected for each configurable feature.

Second, the dependencies of the items are not visible. Depending on the selected product architecture, unique components and connection kits might be required. For instance, type of hydraulic or electric control system defines sets of components, which in practice means different top items. Therefore, very comprehensive product knowledge is required to compare structures like-for-like.

Third, several technical solutions might be available for the same feature or function. Say, a customer configures a certain type of safety feature like emergency stop button. The type of the stop button depends on the selected control system, hence the top items called by configurator might be completely different. This means, the two product configurations fulfilling the same high level customer needs might result in completely different product structures extracted from the configurator.

To sum up, in order to compare product configurations on top item level, even within the same product range, manual post processing is required. In addition, rather detailed level of product knowledge is required in order to be able to compare the essential differences between product structures extracted from the configurator. A simple way to compare the BoMs is crucial when differences in product structures are analyzed.

This ends the overview of the CSA stage, which first analyzed the key stakeholders of the product configuration process. Second, the utilization of product structures in the case company was analyzed. Third, the item parameter assignment throughout process steps was analyzed. Fourth, the OMS and configuration process in the case company was analyzed. Finally, the extracted product structures from the configurator were analyzed. Next, the identified strengths of the current product configuration processes are analyzed.

3.2 Identified Strengths of the Current Product Configuration Practices

As a result from CSA, the identified strengths of the current product configuration practices are collected under three thematic topics. The first topic related to structures consists of strengths in managing the product structures. The second topic related to input consists of strengths in managing the item database and definition of input data for configurator. The third topic related to systems consists of strengths in application of the tools and systems. Next, each topic is introduced.

First, the strengths related to structures are analyzed. The BoMs are commonly applied in cross-departmental manner. The eBoM is acting as the master data, of which the mBoM and sBoM are created, as discussed in 3.1.2 more in detail. The eBoM is utilized directly as such in the sales configurator tool, technical documentation and in service documentation such as spare parts pages and manuals. Regardless of the fact that the data in ERP is not harmonized and descriptive parameters are invalid, it is possible to add tags or assign item groups in the very end of the process. This post processing can be done with very little effort without causing disturbances in the master data or production processes. In practice, the top items can be renamed and regrouped with understandable descriptions rather easily.

Second, the strengths related to input are analyzed. The fundamental functionality is well defined. Each item is identified with a unique article number, which is the main identification element. A separate tool defines the next available article numbers and the PDM system allows only unique article numbers. In addition, each item is linked to unique technical documentation describing the contents. Furthermore, the basic item structure is created automatically based on the design structure. Moreover, during the several transfer steps between different tools, the potential transfer errors are monitored and reported by the system tools. Therefore, the number of possible human errors is minimized in many steps during the item introduction process.

Third, the strengths related to systems are analyzed. Most of the data transfer is conducted automatically, although the process consist of several approval steps and requires confirmation from certain key stakeholders. Therefore, the amount of manual processing is on tolerable level. Occasionally a decision or approval in the process might remain pending, yet the overall process is transparent and hence the progress is visible for relevant stakeholders within the system. Another identified strength was the well-integrated PDM system, which is commonly used among several different product lines within the case company.

Summing up, this type of cross-functional approach is crucial for commonly shared component libraries, modular product design and harmonization of common catalogue components. Moreover, the basic change and lifecycle management of items is in place and the set rules are followed by the organizations. In addition, the reporting tools and most of the relevant data was accessible and in a format which is relatively easy to reprocess for various purposes. Table 7 summarizes the identified strengths of the current product configuration practices.

Table 7. Summary of the identified strengths of the current product configuration practices.

Topic	Summary of strengths
1. Structures	Top items are commonly applied as basis for configurator, production, design documentation and spare parts.
2. Structures	Regardless of the low data quality, items can be relabeled and regrouped with very little effort in the output.
3. Input	The critical basic information is available for each item, such as article number and technical documentation.
4. Input	Item structure creation is automated and based on the design structure.
5. Input	Human errors are minimized between the data transfer steps.
6. Systems	Data transfer mostly automated, tolerable level of manual processing.
7. Systems	Process is transparent and progress is monitored.
8. Systems	Well integrated common PDM systems are used across product lines. Change and lifecycle managements are in place and commonly utilized.
9. Systems	Reporting tools are in place and accessible for relevant persons.

As Table 7 summarizes, the identified strengths related to product configuration practices were categorized under three main topics: input, structures and systems. Next, the identified weaknesses of the current product configuration practices are discussed.

3.3 Identified Weaknesses of the Current Product Configuration Practices

Similar to the previous section, as a result from CSA the identified weaknesses of the current product configuration practices are collected under three thematic topics. First topic related to structures consist of weaknesses in managing the product structures. Second topic related to input consists of weaknesses in managing the item database and definition of input data for configurator. Third topic related to systems consists of weaknesses in application of the tools and systems. Next, each topic is introduced.

First, the weaknesses related to structures are analyzed. The main weakness, which was the initiator of this Thesis, was the difficulty to compare the product configurations due to the lack of intuitive grouping of the items and misleading item descriptions. This challenge applies to comparison of very similar products. Even in case of minor adjustments of the product configuration, manual processing of the items was required in order to compare the structures like-for-like. Moreover, technical dependencies are not clear. Even a minor change in the configurator might result in completely different set of top items in the extracted configurator product structure.

In addition, while different product structures were compared, it was found out that certain top items were very similar to each other, yet the direct material costs were completely different. It seems that the cost development is not actively followed, or alternatively the high costs on certain top items are due to miscalculations or ignored cost management.

Second, the weaknesses related to input are analyzed. No strict guidelines are followed in the very first steps of the item creation process. The item input parameters defined by R&D might be arbitrary and the descriptions are occasionally inaccurate or misleading as the system is not monitoring the content of the free text fields and possible human errors. Another reason for invalid parameters is the fact that many modifications are based on copies of existing items, hence the parameters remain as-is. After all, as only the item number is required for successful item creation, other parameters might be even ignored by the creator. In addition, as analyzed in Section 3.1.3, some of the parameters are not completely, or at all, transferred between systems. Furthermore, the database consists of technical documentation created already decades ago. Hence, the numbering, naming and structuring logic has changed by the time several times. This mixture of different practices is not expected to be harmonized anytime soon as it saves time and effort to utilize parts of the existing design as-such. Therefore, even the latest product configurations consist of very old components.

Third, the weaknesses related to systems are analyzed. Clear ownership of the product configurator was missing. Many actions by the Configurator engineer were performed “as previously” without considering the overall process. In addition, there are several different ways to fetch product related data. Although in the back-end the main source of data is the ERP system, only few persons within the organization have direct access to the database. For example R&D leans on PDM database which is not based on ERP. On the contrary, production engineers lean mainly on ERP as the component consumption and up-to-date information is available there. Order desk and customers are using only the OMS database, which is yet another tool. Moreover, as the information is scattered around different tools, collection of comprehensive data is troublesome. Several tools require also different access levels, which leads to increased internal complexity in terms of maintaining and updating the systems. Table 8 summarizes the identified weaknesses of the current product configuration practices.

Table 8. Summary of the identified strengths of the current practices.

Topic	Summary of weaknesses
1. Structures	Product structures extracted from the configurator are difficult to compare.
2. Structures	Suspiciously high deviation in costs for similar items.
3. Structures	Technical dependencies are not visible.
4. Input	No strict guidelines for item creation in terms of adding item parameters.
5. Input	Parameters are not completely transferred between different tools.
6. Input	Differing old data numbering, naming and structuring logics exist.
7. Systems	Missing ownership and guidelines of the product configuration tool.
8. Systems	Several tools and ways to find the same information.
9. Systems	Complexity due to usage of several different tools and systems.

As Table 8 summarizes, the identified issues were categorized under three main topics: input, structures and systems. Next sub-section summarizes an overview of the CSA results which were the key findings related to identified strengths and weaknesses.

3.4 Key Findings from the Current State Analysis (Data Collection 1)

In order to justify the main focus of this Thesis, all identified weaknesses were listed on a scorecard. Each selection criterion was scored from 1 (low/not feasible) to 5 (high/feasible), after which the total score was multiplication of the criteria. The scorecard is presented in Table 9.

Table 9. Evaluation of the identified weaknesses in a scorecard.

#	Topic	Identified weakness	A. Impact	B. Time	C. Influence	D. Implementable	Total
1	**1. Structures**	**Product structures extracted from the configurator are difficult to compare.**	**4**	**3**	**4**	**4**	**192**
2	**2. Structures**	**Suspiciously high deviation in costs for similar items.**	**5**	**3**	**2**	**2**	**60**
3	**3. Structures**	**Technical dependencies are not visible.**	**4**	**2**	**3**	**2**	**48**
4	6. Systems	Missing ownership and guidelines of the product configuration tool.	3	2	3	2	36
5	3. Input	No strict guidelines for item creation in terms of adding item parameters.	2	3	2	2	24
6	5. Input	Differing old data numbering, naming and structuring logics exist.	2	2	2	2	16
7	8. Systems	Complexity due to usage of several different tools and systems.	2	3	2	1	12
8	7. Systems	Several tools available to find the same information.	2	2	1	1	4
9	4. Input	Parameters are not completely transferred between different tools.	3	1	1	1	3

As seen from Table 9, the criteria were estimated impact on business benefits (A), time limitation of this thesis work (B), possibilities to influence the change (C) and easiness of implementation (D). As a result, the identified weaknesses were ranked based on the total score. Three topics with the highest total score were selected for further comparison, which are discussed next more in detail.

The third highest score: *technical dependencies are not visible*. The structural dependencies between different top items are not visible and not always understandable. This results in complex configuration rules as by selecting a feature, the system may force the selection of certain other top items. This results in requirement of very thorough product knowledge and seemingly illogical selection. Especially for Front line units and Sales persons the configuration logic must be easy and understandable in order to react fast in request for quotations. Therefore, the quotation process remains complex, which is expected to impact on the sales as well.

The second highest score: *suspicious high deviation in costs for similar items*. This topic is very interesting for the case company as managing the costs will have strong impact in profitability. As the top item costs were not aligned, uncontrolled cost structures are very likely to result in high costs and reduced profitability.

The highest score: *Product structures extracted from the configurator are difficult to compare*. As the top item categorization is not aligned, it results in lack of transparency and clarity in product management. This is furthermore expected to result in challenges to compare different products and product configurations, as well as understand how the product costs are divided among the different item categories. It is also very challenging to find out configuration mistakes from the product structures extracted from the configurator. Possible configuration mistakes typically cause major disturbances in production flow. Hence, unclear product configurator output results in laborious internal processes when comparing configurations and increased risk of undetected configuration mistakes.

Out of these three major topics which resulted from CSA, from hereafter this Thesis will focus to *rationalize the product structures extracted from the product configurator*, resulting highest score in Table 9. The main reason for the selection compared to the other high ranked topics is the possibility to influence the changes and implement the changes within the time frame of this Thesis. The next section reviews the found best practice related to product configuration management from the literature.

4 Best Practice on Product Configuration Management

This section discusses best practice related to management of product configurations. Best practice from the literature were collected in order to overcome the identified weakness resulting from CSA in Section 3, to *rationalize the product structures extracted from the product configurator*. First, an overview on the building of conceptual framework is provided. Second, the found best practice on configurable product offering are discussed. Third, the found best practice on product structure management are discussed. Fourth, the found best practice on configurator output are discussed. Finally, the conceptual framework for this Thesis is presented.

4.1 Overview of Found Best Practice on Product Configuration Management

The found best practice from literature is divided in three elements. As most of the studies related to configurator tools are context dependent, the literature reviews were selected from different sources in order to capture similarities relevant for the case company context.

The first element discusses the *Configurable Product Offering*. In literature, product configuration process includes also the supply chain and component ordering (Tiihonen et al. 1995). In this Thesis the *configuration of a product* refers to process, which is named in some of the references as *sales specification process*. Sales specification process is further in detail divided into interaction with the customer, which includes product specification process (Kristjansdottir et al. 2018) in which the product is actually configured. Furthermore, the product is configured based on selected features from a pre-defined catalogue (Shamsuzzoha et al. 2011). Given this, the catalogue is built based on the available top items. This makes a logical step to examine the product structure management more in detail.

The second element discusses the *Product Structure Management*. The configuration specified by the customer is converted into set of top items. This fully specified product configuration may be further processed in desired presentation of the structures. (Van Veen, 1991). There are several different approaches to deal with the resulting configurator output, introduced later in this section.

Figure 6 provides an overview of the literature review, including all these three parts.

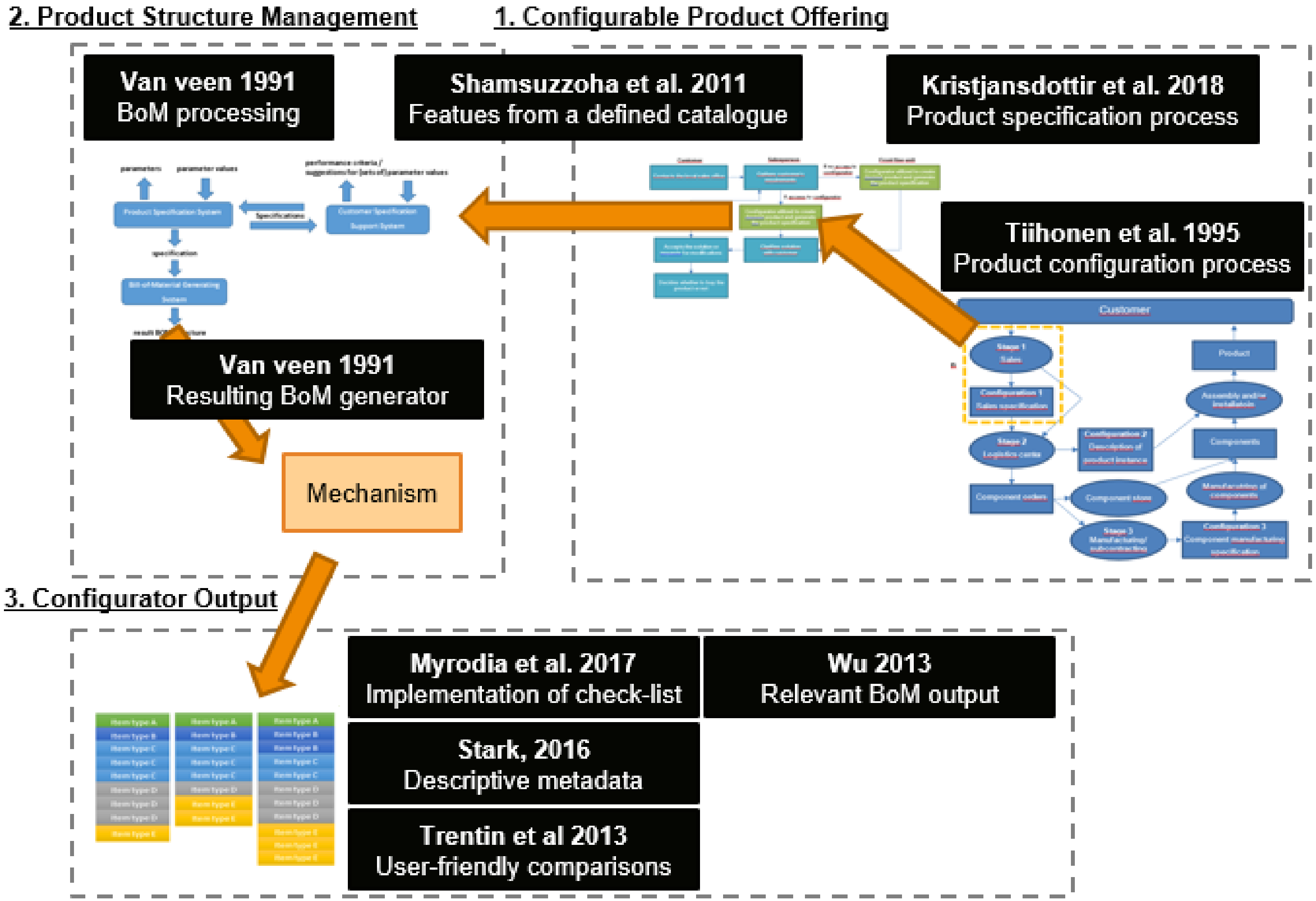

Figure 6. Overview of the literature review.

As seen from Figure 6, the third element discusses *Configurator Output*, which may be further refined. First, although the configuration processes are typically automated, the implementation of check-lists is suggested (Myrodia et al. 2017). Second, the relevant output of the structures depends on how they are utilized further (Wu, 2013). Third, the application of descriptive metadata is suggested in the literature (Stark, 2016). Lastly, user-friendly comparisons were proven to provide benefits for the users of configurator. (Trentin et al. 2013).

Figure 6 summarizes the literature review consisting of three elements, which are discussed more in detail in the following sub-sections. Finally, Section 4.5 introduces and illustrates the conceptual framework for this Thesis and concludes the literature review.

4.2 Best Practice on Configurable Product Offering

First of all, a *configurable product* has a pre-designed product structure, which is adapted by a routine or a systematic *product configuration process*. The product structure consists of pre-designed top items, or groups of top items, which are collected during the configuration process according to the requirements of a customer. The product configuration process mainly forces the customer to select from already existing components, yet some modifications might be allowed. (Tiihonen et al. 1995:3) Figure 7 gives an overview of the product configuration process.

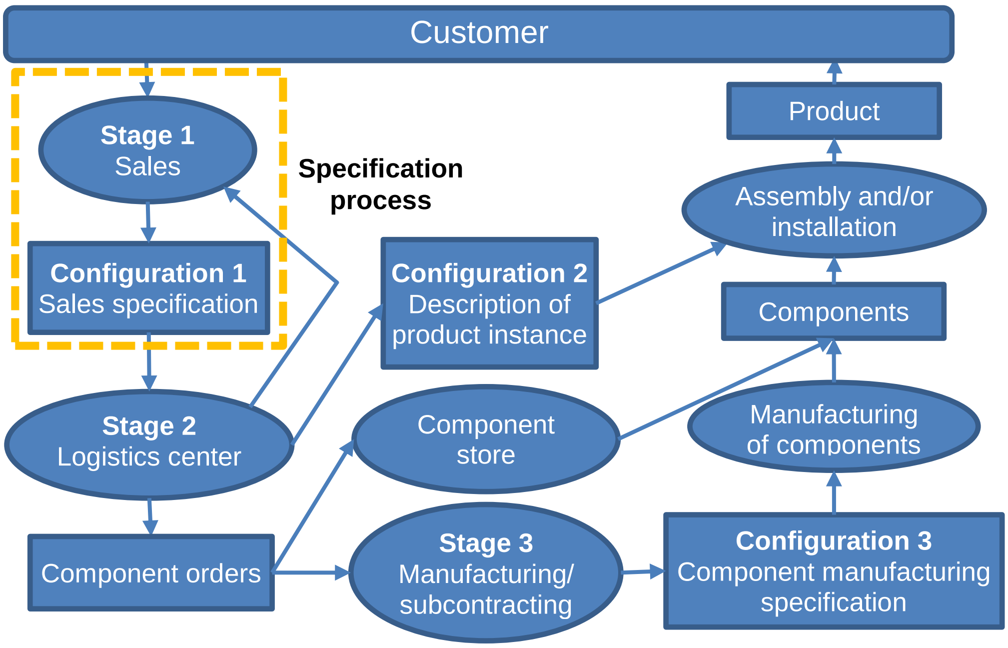

Figure 7. The configuration process (Tiihonen et al. 1995:7).

As Figure 7 shows, the first step the customer interacts with the sales unit, which creates the sales specification, or configuration 1. The requested specification is forwarded to logistics center, which translates an order into configuration 2 which creates component orders to production units and suppliers. An order confirmation is sent back to sales and the component orders are forwarded to component store and manufacturing. In some cases the ordered components are configurable products themselves, hence the configuration 3 is included in the process. After the components are delivered, the assembly is completed and eventually the product is shipped to the customer.

The *specification process* highlighted in Figure 7 also contains a sub-process. Figure 8 illustrates the product specification process for configurable products. First, a customer interacts with the salesperson. The sales person collects the customer requirements and feeds the requested features in the product configurator. In case of limited access, salesperson contacts the company front line unit. Either way, the desired product configuration is created and a summary or a preview of the order confirmation is provided to the customer. Customer accepts the proposal or requests further modifications which might require another iteration through the configurator. Eventually the configuration is as close to the original request as possible and the customer makes the final decision whether to buy the product or not.

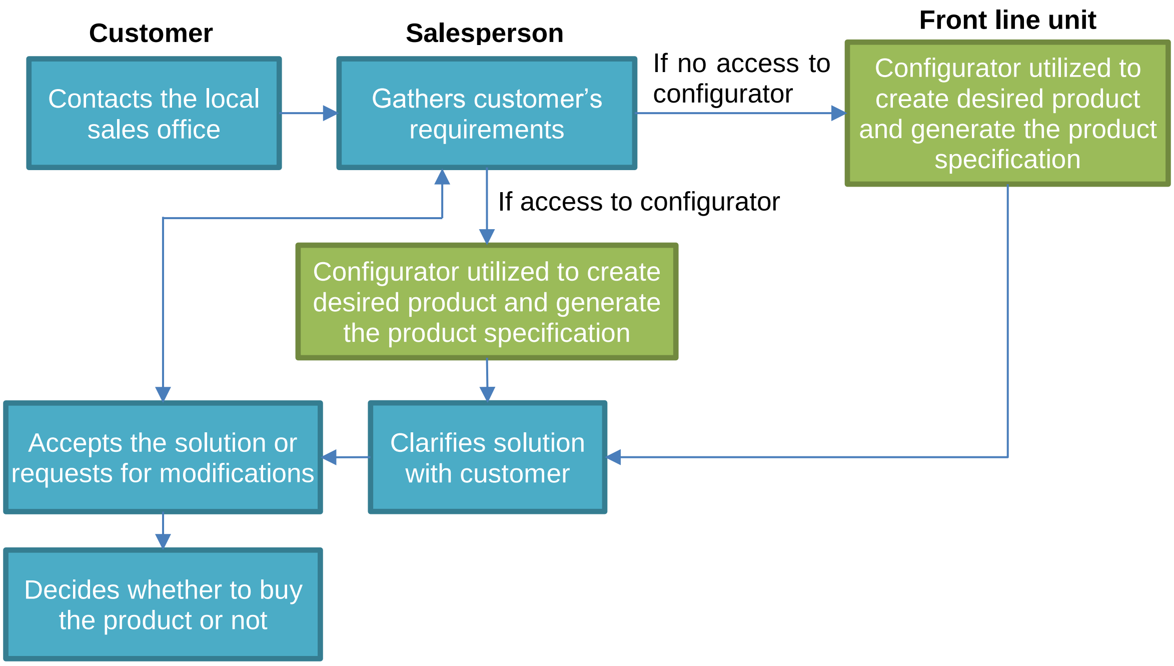

Figure 8. The product specification process for configurable products (Kristjansdottir et al. 2018:64).

Although a well-defined configuration tool reduces -or removes completely- configuration mistakes, disturbances in the delivery and configuration process are still possible. At least two common types of issues are reported in the literature. First, customers change the product configurations after placing the order. However, in some industries this is law of the nature and the increased flexibility provides a competitive advantage. Second, the complex internal delivery processes commits errors. Companies delivering customized solutions might waste portion of their annual sales solely in delivery process inefficiencies. (Tiihonen et al. 1995:8)

In the same way, companies are facing problems related to product configurations. Some known problem areas are identified in the literature. First, it is difficult to estimate the economic importance of configurable products. Second, the configuration task itself may turn out to be rather complex. Third, the configuration process is challenging to merge to other company processes. Fourth, product families evolve and hence it creates a need for management of product knowledge as well as configuration knowledge over a long time span. Finally, the interfaces to other tools and systems makes the management of configuration process and information flow much more complex. (Tiihonen et al. 1995:5-10)

Moreover, the main benefits of utilizing a configurator tool are significantly reduced time for offer and technical specification preparation, product configuration process, quotation and tendering process as well as for offer preparation. In addition, data quality is improved, number of configuration errors significantly reduced and accuracy of pricing and specification is increased. (Kristjansdottir et al. 2018:59).

This section discussed the configurable product offering and configuration process. Once the desired product configuration is created, it will be converted to product structures. This summarizes the first element of the conceptual framework of this Thesis. Next, best practice on product structure management are discussed.

4.3 Best Practice on Product Structure Management

To begin with, the market dependent and customer specific requirements have imposed to a necessity on the manufacturing companies to offer a large variety of products. Hence, manufacturing companies create product families to offer a number of variants of products with limited development and manufacturing costs. Ideally, the product variants offer numerous functional differences with smallest possible number of items and physical components. (Erens & Verhulst, 1997:165,175) However, the available product variants are meaningful to customer only if the functionality varies in some way (Ulrich 1993:428). In order to manage the increasing level of product differentiation, companies are applying a configure-to-order (CTO) approach. CTO allows customer to select the desired product features from the pre-defined catalogue prepared by the company. (Shamsuzzoha et al. 2011:1-2)

Subsequently, when the initial product structure is created, it often focuses either on engineering design or manufacturing design. Designers prefer functional oriented structures, whereas manufacturing prefers structures which are easier to apply in existing manufacturing processes. (Adolphy et al. 2015:154) Moreover, also other departments have different requirements for the resulting structures. For example design department is mainly focusing on creating product structures out of design BoM, whereas production engineering department reorganizes the BoM to fit the production layout. (Wu 2013: 775) Furthermore, the creation logic of BoMs is not limited only to application domain. In literature, several BoM variants are presented based on the product lifecycle phase, such as beginning-, middle- and end-of-life structures. (Zhou et al. 2018:147-148)

Likewise, different kind of descriptions for same BoMs might be necessary. Although the BoMs for manufacturing and engineering are identical, an additional difference may arise as they have different assembly descriptions. As an example, the same products with identical BoMs are to be assembled in different assembly sites. In some cases, alternative ways to assemble the same set of assembly parts exist. Eventually the products need to be recognizable in the prescribed operations. Hence, different kinds of product descriptions may describe different aspects of a product. (van Veen 1991:187-188)

However, the primary interests for the sales function are products rather than the product structures. Therefore, two contradictory demands play a role. First of all, order-independent and explicit definition of product structures should be avoided. On the contrary, the available product structures should be described in detail for a particular order, without being explicitly defined beforehand. In other words, the configurable structures should be created in such a generic way, that even without testing each configuration, customer could freely select any suitable configuration. Therefore, a finite set of parameters need to be defined in such a way that they are relevant to the viewer. All allowed configurations need to be distinguished into unique configurations with valid parameters. (van Veen 1991:9-11,30,45,48)

In addition, the need for a customer specification support system arises in case of non-trivial relationships exist between product properties and the performance of the final product. Typically this type of support is required by the customer, since the customer is aiming to fulfill the functional requirements. On the contrary, the configurator selections are related to technical properties or parameters. For example, a customer considers performance of a vehicle in terms of top-speed or fuel consumption. However for the configurator the product is to be described in terms of parameters such as gross weight, wheelbase and suspension type. (van Veen 1991:49) Figure 9 shows an architecture of BoM processing which aims to achieve a valid specification with most suitable parameter values for the customer.

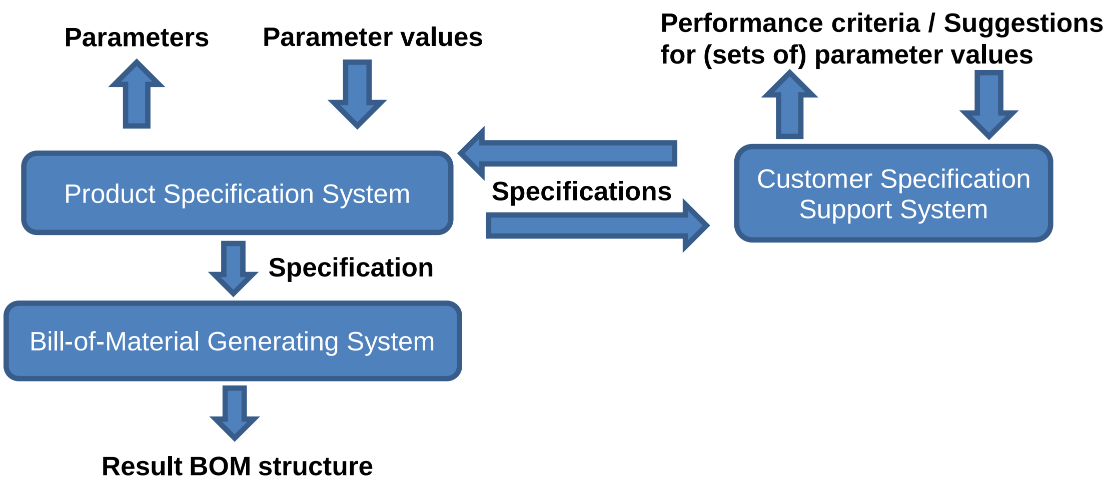

Figure 9. An architecture for BoM-processing (van Veen 1991:48).

As Figure 9 shows, the customer specifies product properties or performance criteria. With the support of product specification system -or a product configurator- the most suitable configuration is proposed. Dependencies between product properties and performance criteria often cannot be represented unambiguously, hence the conversion between customer and product specifications. Furthermore, the product specification is eventually generated into relevant product structures for further processing. Figure 10 illustrates the process of generating a result BOM from a full specified input.

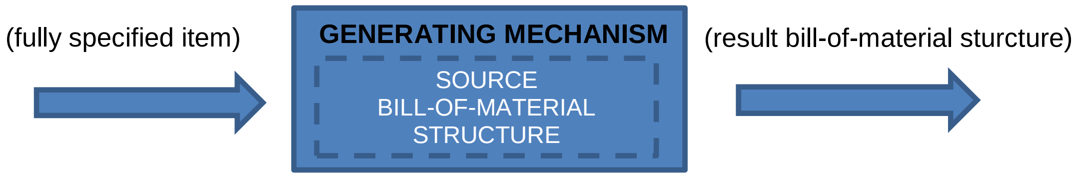

Figure 10. The process of generating a result BOM-structure (van Veen 1991:54).

This section focused on best practice on product structure management. In short, a product configurator aims to fulfill a customer request. Once the suitable customer configuration is selected, it is converted into product specification. The product specification is further processed into relevant product structures, which can be presented in many various ways. This summarizes the second element of the conceptual framework for this Thesis. Next, best practice on configurator output are discussed.

4.4 Best Practice on Configurator Output

In literature, the term configurator is used to develop customized products or services. However, the configurator may be divided more in detail to deal with customer demands and required features (customer oriented configurator), sales items such as pricing and delivery time (sales configurator), design and engineering items such as BoM (product configurator) or to set operational routings and planning production resources (production configurator). (Shamsuzzoha et al. 2011:1-2) In this Thesis, the product configurator refers to combination of the previously mentioned features as all the functionality is merged to a common software tool. Next, best practice related to configurator output are discussed.

First of all, successful implementation of a configurator tool improves the efficiency of quotation process. However, operational configurator tool requires thorough testing as creation of configuration rules requires good command of complex item relationships. Therefore, implementation of checklists at the end of configurator might help some companies to improve the general performance. (Myrodia et al. 2017:16)

Second, the delivered configurations must be managed and there must be a possibility to trace them afterwards. If the configuration is not maintained, eventually the configuration documentation no longer corresponds the delivered BoM. This will lead to increased scrap, rework and stock. Furthermore, issues in the field are difficult to resolve if it is not known exactly which components the product contains. (Stark, 2016:149)

Third, a formal description of product data is important. Clear and consistent description improves the management of data and hence defines a system language. The defined system language is to be followed within the company to avoid unnecessary misunderstandings. Therefore, item numbers must be unique in order to identify every single specification and control the changes. (Stark, 2016:152)

Fourth, items should contain a short description or title block which contains descriptive metadata. Descriptive metadata of an item helps to identify and manage the actual data. Sorting of databases may be simplified even with very limited number of metadata identifiers. Metadata can include for example general description, product family type and configuration rule, which supports further the sorting of databases. (Stark, 2016:171-172)

Finally, easy comparison of configurations minimizes the effort to compare previously created configurations. Presenting the differences in product configurations helps the potential customer to understand the differences, such as weight or cost between the selected configurations. The potential customer, or user who is configuring the product, does not need to rely on memorizing or computational abilities to find out similarities and differences. (Trentin et al. 2013:439)

This section discussed best practice on configurator output. The emphasis was put on implementing check-lists as a safety measure for configuration errors, focusing on maintaining the structures for aftermarket purposes, agreeing a clear system language, adding metadata and creating the configurator output in comparable way. This summarizes the last, third element of the conceptual framework of this Thesis. Next, the conceptual framework is discussed.

4.5 Conceptual Framework of This Thesis

The conceptual framework of this Thesis consists of three main elements which were introduced previously in this section. All three elements aim to *rationalize the product structures extracted from the product configurator*. Figure 11 shows a visual representation of the conceptual framework.

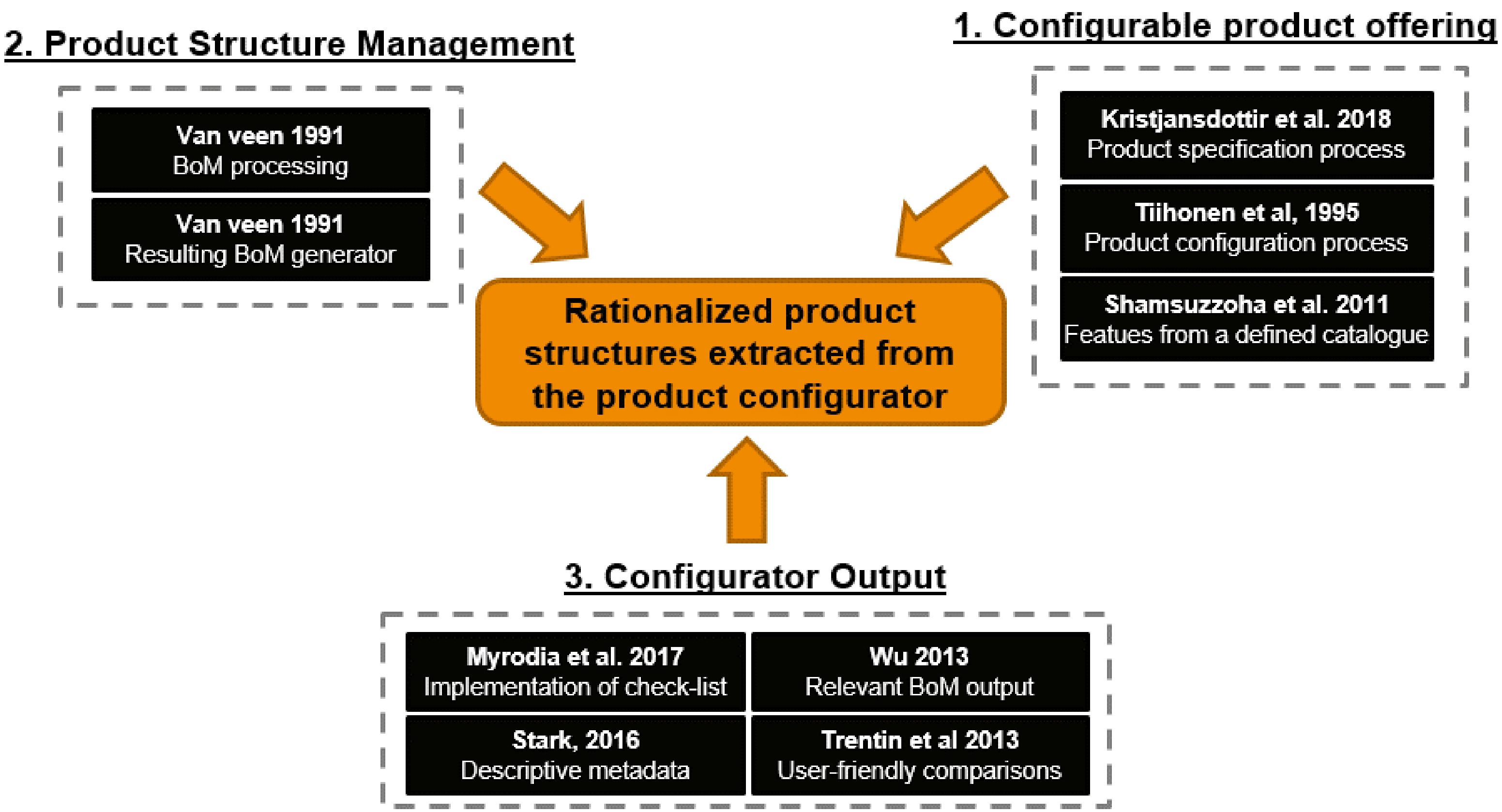

Figure 11. Conceptual framework of this study.

As seen from Figure 11, the conceptual framework is divided in three main elements.

The first element of the conceptual framework is the configurable product offering. A specified product configuration drives the internal process of the company, such as component ordering and production planning (Tiihonen et al. 1995). The requested product configuration is created in a sales product specification process which involves the customer and sales person (Kristjansdottir et al. 2008). The product configuration tool is a critical connection node between these two processes, as a configuration is needed both to create a demand for production, as well as to describe the features for the customer. The configuration tool acts as an interface between production and sales unit, as the available configurations are pre-defined and hence the sales channels are leaning on pre-defined features on a catalogue (Shamsuzzoha et al. 2011). Once the configuration is defined, it will be processed further and required BOMs will be created.

The second element of the conceptual framework is the product structure management. The pre-defined specification is further processed into BOMs (Van veen 1991). The source BOMs are generated into result BOMs via generating mechanisms (Van veen 1991). The resulting BOM structures are set in pre-defined formats depending on the intended further usage.

The third element of the conceptual framework is the configurator output. Resulting BOMs are utilized for different purposes. For example production BOM is defined to create demands for components, order confirmation BOM as a check-list for quality department and sales BOM for customer as an order confirmation (Wu 2013). Implementation of check-lists for the resulting BOMs is advised to maintain the control and avoid possible mistakes especially after updates in the process or systems (Myrodia et al. 2017). The resulting BOMs should be easily comparable for troubleshooting, further development and to be clear also for inexperienced persons to understand differences of the configurations (Trentin et al. 2013). Descriptive metadata should be used to distinguish and identify items inside the BOMs (Stark 2016). Labeling items with descriptive metadata supports grouping of similar items, which supports further post-processing of the BOMs.

Finally, the three above discussed elements creates the conceptual framework of this Thesis. This conceptual framework is utilized in the proposal building which aims to rationalize the product configurator output. The proposal building is discussed next, in Section 5.

5 Building Proposal on Rationalizing Product Structures Extracted from Configurator

This section combines the results from the current state analysis, discussed in Section 3, and the conceptual framework, discussed in Section 4, towards the building of the proposal which incorporates Data 2.

5.1 Overview of the Proposal Building Stage

The goal of this section is to provide an overview of the key elements of the initial Proposal. Furthermore, the logic of building the initial Proposal is explained.

First, Section 3 discussed the results from CSA of product configuration output of the case company. The main identified weakness was related to difficulties to compare the extracted product structures form the product configurator. Hence, the objective of this Thesis is to *rationalize the product structures extracted from the product configurator*.

Second, Section 4 discussed found best practice from the literature related to the topic. Based on the findings, the Conceptual framework was introduced which based on several literature references related to Configurable product offering, Product structure management and Configurator output.

Finally, with these in mind, a draft of the initial Proposal was created. This draft was further modified according to suggestions from the key stakeholder, explained next.

The proposal building was conducted in cooperation with the Configurator engineer, who was able to clarify limitations and opportunities related to the existing tools and configuration logic. The proposal building was completed as follows. First, the current state was examined. Second, all active top items were extracted, re-labeled and grouped. Third, the system limitations were discussed more in detail with the configurator engineer. This made the Data 2. Fourth, the regrouped top items were prepared in suitable format to be introduced to the product configurator tool. Finally, the Initial proposal was prepared. The findings of Data 2 collections are discussed next.

5.2 Findings of Data 2 Collection

A workshop-like conference call was arranged to collect input data from the key stakeholder to the Proposal building. The key stakeholder to the Proposal building was the Configurator engineer. Other relevant stakeholders were the Product managers, yet the focus of this Thesis is related to operative level. Hence, the Configurator engineer was the key person to provide suggestions related to practical implementation and operation in the live environment.

The findings related to the results from CSA were summarized together with the Conceptual framework. Overview of the suggestions from the configurator engineer are summarized in Table 10. The suggestions are divided into relevant categories including the main focus area in results from CSA (topic 1) and CFW (topics 2-5). For each discussed topic, the suggestion was summarized and explained.

Table 10. Key stakeholder suggestions for proposal building (Data 2) in relation to results from the CSA and the key elements of CFW.

	Topic	*Suggestions from stakeholder*	*Description of the suggestion*
1	CSA: Product structures extracted from the configurator are difficult to compare.	a) Grouping of items should not be too detailed for easier maintenance b) Full list of groups and items needs to be provided, it would be good to distinguish production components and sales options.	a) The Configurator engineer suggested to divide the top items in controllable number of groups to avoid future challenges to decide grouping of new items. b) Regrouping is possible, yet there are system limitations in number of characters for the codes and descriptions. Both top items and sales options are defined with a code, hence they need to be distinguished.
2	CFW: Resulting BoM generator	The fully configured BoM can be regrouped and the order of extracted items can be changed.	The extracted product structures from configurator may be listed in groups. In addition, the listing order of these groups can be predefined for more understandable appearance.
3	CFW: Implementation of check-lists	Same tools can and should be used as they are already proven to work well.	Configuration checks are performed already today, yet the proposal is expected to decrease further the number of configuration errors.
4	CFW: Descriptive metadata	Descriptive data should remain in rather high level.	Very detailed descriptions and especially item descriptions related to specific product versions and models should be avoided. Common items are used in many different products.

5	CFW: Relevant BoM output	Only relevant items should be visible in the extracted item list.	The extracted item list is applied also by production, quality department and customer. Hence, all items which are expected to be delivered with the product must be visible.
6	CFW: User-friendly comparison	The group descriptions should be understandable and in English to maintain consistency. System limits to be respected.	Today the grouping codes are partly overlapping in terms of naming, and the descriptions are based on old coding logic and different languages which makes the database maintenance challenging.

Next, the three elements of the initial Proposal are discussed. First, the identified strengths which are to be embedded in the initial Proposal are explained more in detail. Second, the applied parts of CFW are discussed. Third, the stakeholder input is explained more in detail. Finally, the proposal draft is summarized.

5.3 First Element of Proposal: the Identified Strengths in CSA

To start with, the existing system architecture and tools are utilized in the proposal. As discussed in Section 3.2, the strengths identified in CSA were related to product structures, input data and systems. The strengths relevant for the proposal building are now discussed.

First of all, several strengths related to systems were identified. The existing tools supported the proposal building and there was no need to interfere the back-end automated operations. Moreover, the configuration process steps were in place and followed by the organization. Hence, all required functionality was in place yet not completely utilized.

Figure 12 summarizes the relevant features of the existing system. The fully specified configuration is fed as input to the configurator tool, which extracts the product structures to be further processed. This whole process step is embedded in the product configurator, which is illustrated with dashed rounded rectangle.

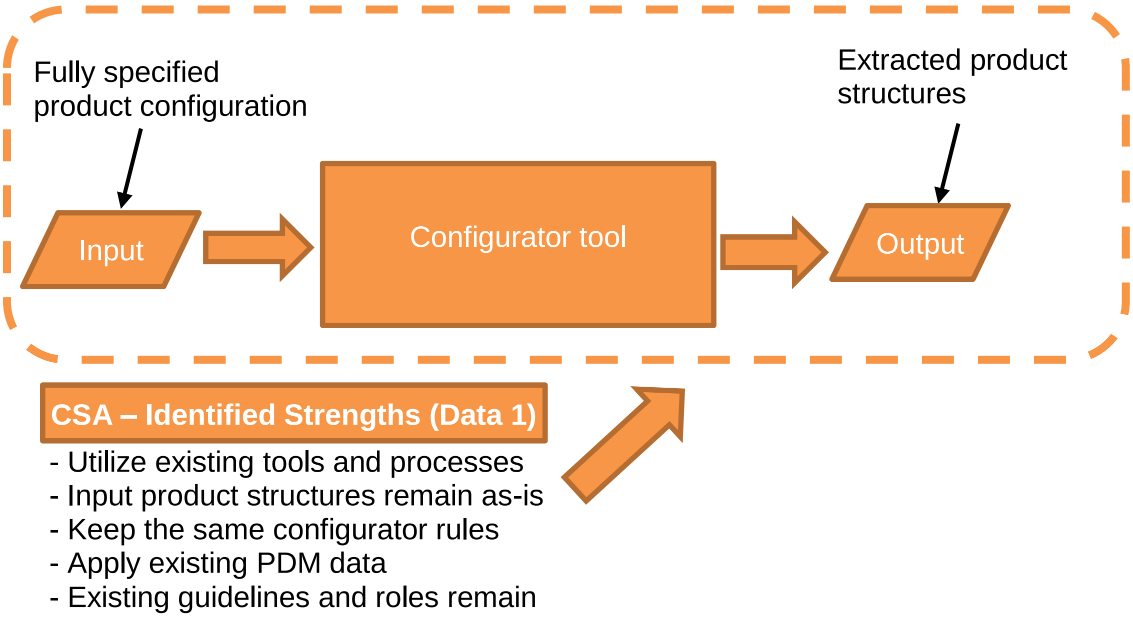

Figure 12. Identified strengths related to initial Proposal building.

Furthermore, as Figure 12 shows, the existing system tools and way of dealing the product data remains as-is. As the intended modifications are aimed to be performed in the very last steps of the process, there is no need to modify the input data or rework the configuration rules.

To summarize, the current setup is maintained to avoid jeopardizing the existing benefits. Input data remains as-is, only the top items inside the product structures are intended to be reorganized in groups based on PDM data. The updates are made in the existing configurator tool, hence no manual processing is needed after the groups are assigned. This was the first element of the initial Proposal building. Next, the implementation of the Conceptual framework is discussed.

5.4 Second Element of Proposal: the Conceptual Framework

The second element of the initial Proposal is the Conceptual framework which utilizes best found practices from the literature. The CFW was divided into three elements: Configurable product offering, Product structure management and Configurator output.

First, the Configurable product offering focuses on processing of data before the actual product configurator. The existing methods support best practice, which suggests i.a. successful ways to specify a product configuration and application of pre-defined catalogues on basis of the selection. These practices exist already in the current setup.

Second, the Product structure management is embedded in the initial Proposal. Processing of product structures and especially the resulting product structure generator is the key element of the Proposal. A generating mechanism deploys the fully specified product configuration and converts it into desired output. Such a mechanism is already embedded in the existing product configurator, yet it is utilized poorly. The existing configurator environment is highlighted with the orange dashed rounded rectangular shape in Figure 13.

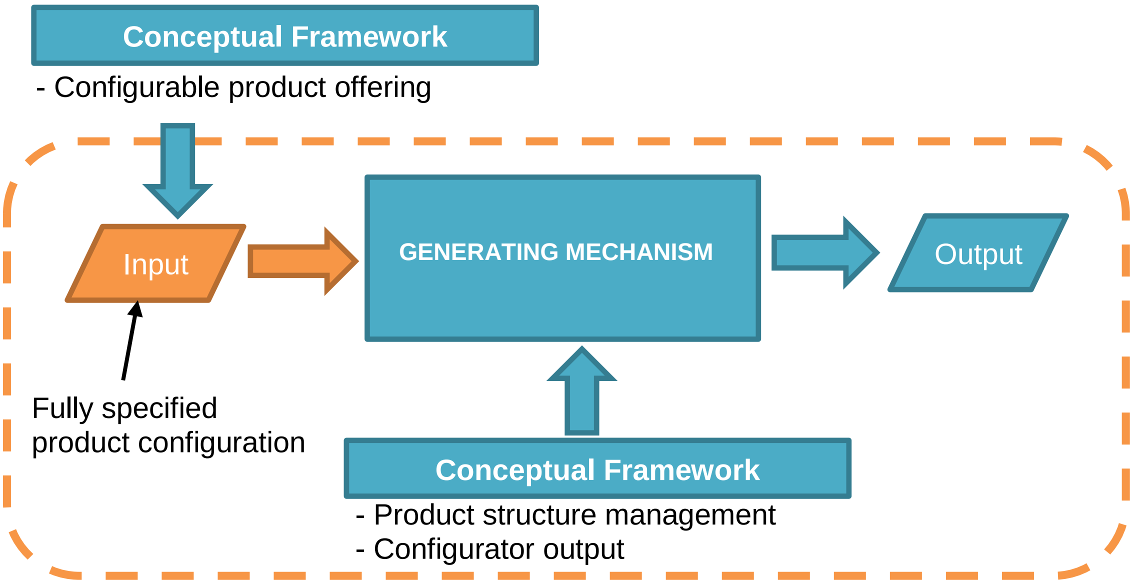

Figure 13. Conceptual framework embedded to the initial Proposal building.

Third, best practice related to Configurator output is utilized in the generating mechanism as shown in Figure 13. The fully specified product configurations are further reprocessed by assigning top items into pre-defined groups. The output is hence a list of top items of which each contains group identification label with descriptive metadata.

To summarize, the CFW is embedded into the existing tools. In practice, a generating mechanism is programmed to group top items in requested order. Hence, the output can be defined in such a way that the extracted product structures are rationalized. Next, the implementation of suggestions from the key stakeholder is discussed.

5.5 Third Element of Proposal: the Stakeholder Input (Data 2)

The third and last element of the Initial Proposal is Data 2, which consisted of key stakeholder input. The key stakeholder, the Configurator engineer, provided suggestions both to results from CSA and to the applied elements of the CFW.

The first part of the feedback was related to the results from CSA consisting of two suggestions. First, the grouping of items should remain in rather high level in terms of metadata. Hence, the future maintenance of the configurator is easier. Second, as the sales options and top items are both coded in the configurator, therefore the type of coding should differ in order to easily distinguish the sales options from the top items.

The second part of the suggestions was related to the elements of the CFW. Data 2 was discussed already previously in this section, hence only relevant items are now summarized. Figure 14 presents the stakeholder input to the generating mechanism.

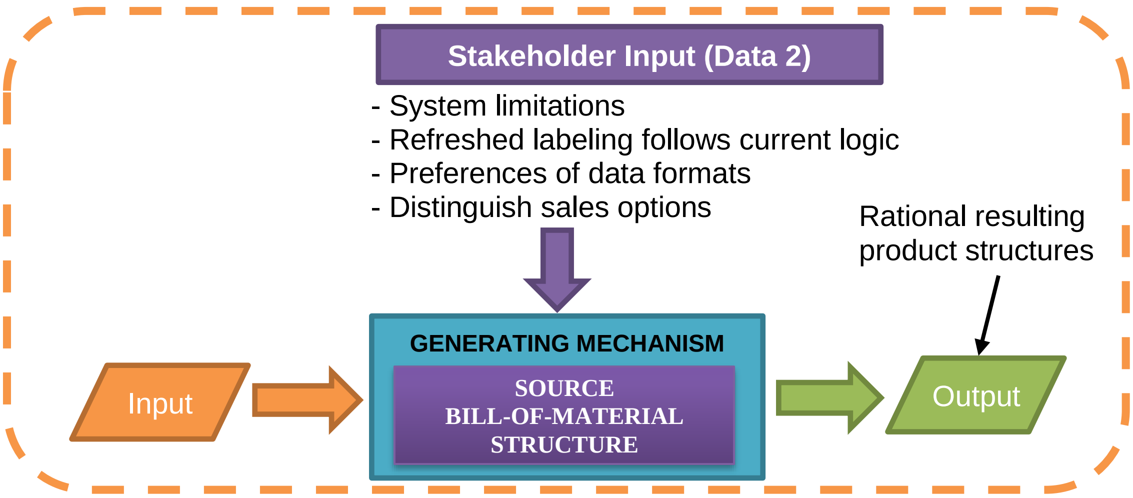

Figure 14. Stakeholder input embedded to the initial Proposal building.

As seen in Figure 14, the relevant stakeholder input to the initial Proposal consisted of several suggestions. First, the group codes and descriptions should remain within the number of allowed characters. The group identification code should consist of no more than 10 characters whereas the description of the group is allowed to be up to 100 characters.

Second, the coding logic and descriptions should be logical, coherent and understandable. Therefore, the naming should be defined in English language as that is also the company language in this case. The current hard-coded configurator logic should be followed in order to avoid possible modifications which might require a lot of effort in terms of testing and validation to maintain even the same functionality.

Third, also the future grouping of items should remain easy. Therefore, very detailed or complex way of description and dividing groups should be avoided. Simple high level grouping is preferred for easier data handing in the future, especially in case of new items.

Finally, the configurator tool mainly deals with two types of codes. The first type of coding is applied for top items, which eventually define the extracted product structures. The second type of coding is applied to build the configuration logic for the sales options. Therefore, it was requested to implement grouping codes, from which would be easy to distinguish the production related codes from the sales option codes. This reduces the complexity in setting new configuration rules.

To summarize, the Stakeholder suggestions mostly consisted of practicalities related to application of the existing configurator tool. However, for example the possibility to predefine the order of the groups further improves the comparability of different configurations. Moreover, as the existing tools are applied, it is important to consider the opportunities and limitations in the building of initial Proposal. This summarized the third and last element of the initial Proposal. Next, the Proposal draft is discussed.

5.6 Proposal Draft

The Proposal draft consists of the three previously introduced elements in this section. Figure 15 draws together the Proposal draft, which is next discussed more in detail.

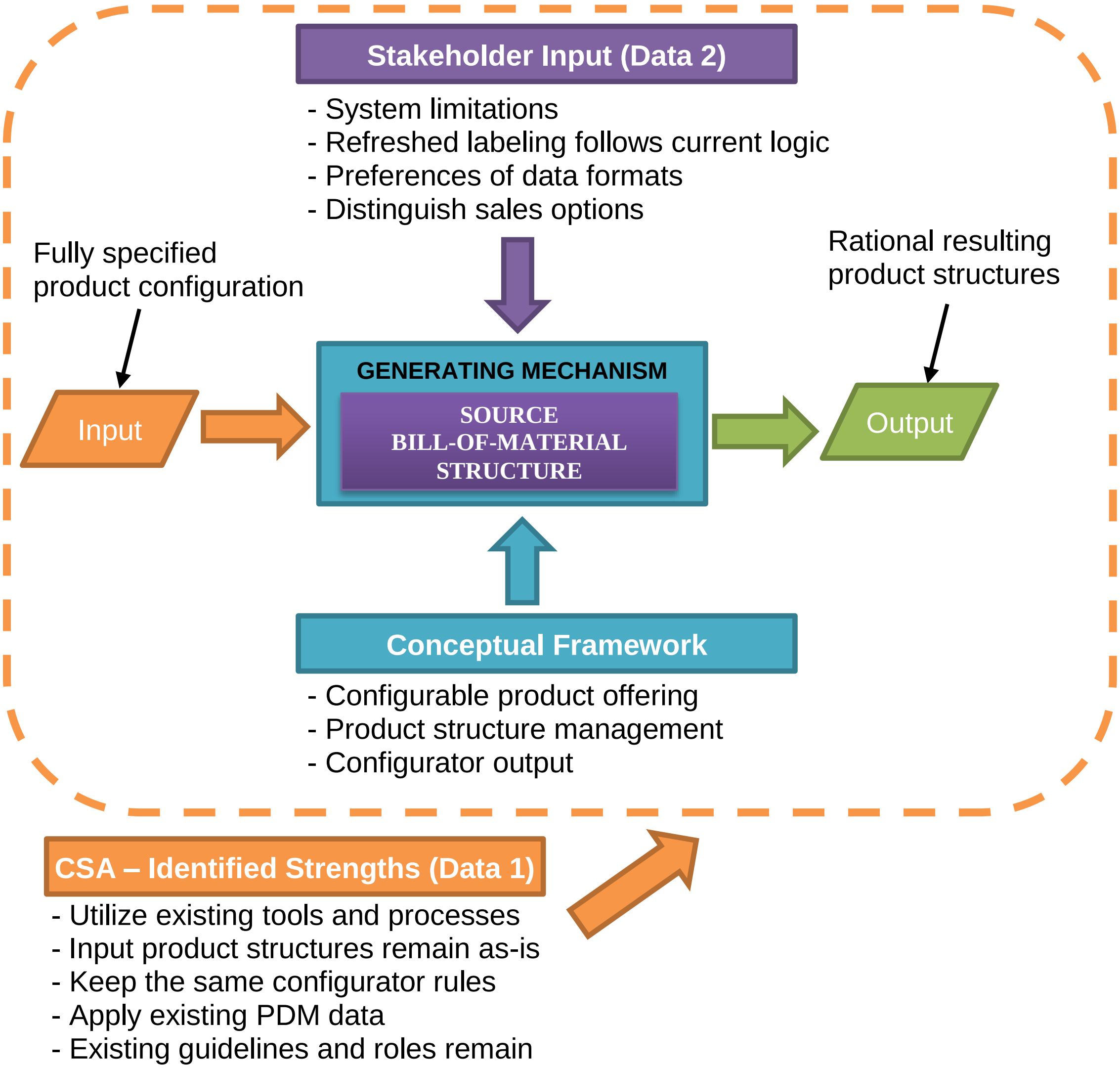

Figure 15. Initial proposal for Configurator output generator (pulled together based on CSA, CFW and Data 2).

Figure 15 shows the initial proposal for *Configurator output generator*, which is a post processing step in the product configurator tool. The generating mechanism plays the main role in the Proposal draft. The fully specified product configuration acts as an input to the generating mechanism, labeled now as the Configurator output generator, which reorganizes and groups the structures in a defined manner. Finally, the output will be rationalized product structures extracted from the product configurator. The outcome of the mechanism is illustrated with green color in the picture. Next, the three elements of the proposal shown in Figure 15 are briefly explained.

First, all the functionality is available and built in to the existing tools and processes, which were found to function very well in the results from CSA. The identified strengths from CSA are illustrated with orange color. Hence, the planned modifications will be made in the front-end instead of updating the back-end databases such as PDM or actual design structures. The planned updates are more related to visualization and sorting of the relabeled data without making any changes in the input data.

Second, the conceptual framework is applied in the Configurator output generator. The CFW related topics are illustrated with aqua blue color. Especially the two elements related to Product structure management and Configurator output are utilized to a great extent in the practical proposal.

Third, the stakeholder input is included in the Proposal draft. The stakeholder input, which makes most of the Data 2, is illustrated with purple color. Practicalities and boundary conditions such as the type and limitation of the existing system were clarified. In addition, proposed suggestions and preferences were taken into account. Suggested topics were incorporated in the Proposal draft, such as the preferred data format to define the groups easier, as well as the preferences how different types of items will be distinguished.

Finally, these three elements define the Proposal draft of the Configurator output generator. The Proposal draft combines the identified strengths resulting from CSA, CFW and feedback from key stakeholder (Data 2). This initial Proposal of Configurator output generator aims to rationalize the extracted product structures from the product configurator. Next, the validation of the initial Proposal is discussed in Section 0.

6 Validation of the Proposal

This section validates the proposed draft of Configurator output generator developed in Section 5, discusses the results of the validation stage and evaluates the further development of the initial Proposal. At the end of this section, the final Proposal and recommended further actions are presented.

6.1 Overview of the Validation Stage

The goal of this section is to demonstrate the logic of the validation steps as the initial Proposal is refined towards the final Proposal. First, an overview of the applied validation is provided. Second, the key findings of Data 3 collection are summarized. Third, the developments to the Proposal draft based on Data 3 are introduced. Fourth, the final Proposal is introduced. Finally, the recommended next steps are discussed in the end of this section.

The Proposal aims to solve the main weakness identified in the results from CSA, which was *product structures extracted from the configurator are difficult to compare*. The objective for the proposal is to *rationalize product structures extracted from the product configurator.*

The complete validation phase consists of three steps, as illustrated in Figure 16. Out of these steps, only the Step 1, piloting, is included into the scope of this Thesis. Step 2 and Step 3 will be performed in the near future. Each of these validation steps includes discussion with the key stakeholders. Moreover, each validation step is completed only after the relevant modifications are implemented to the proposal.

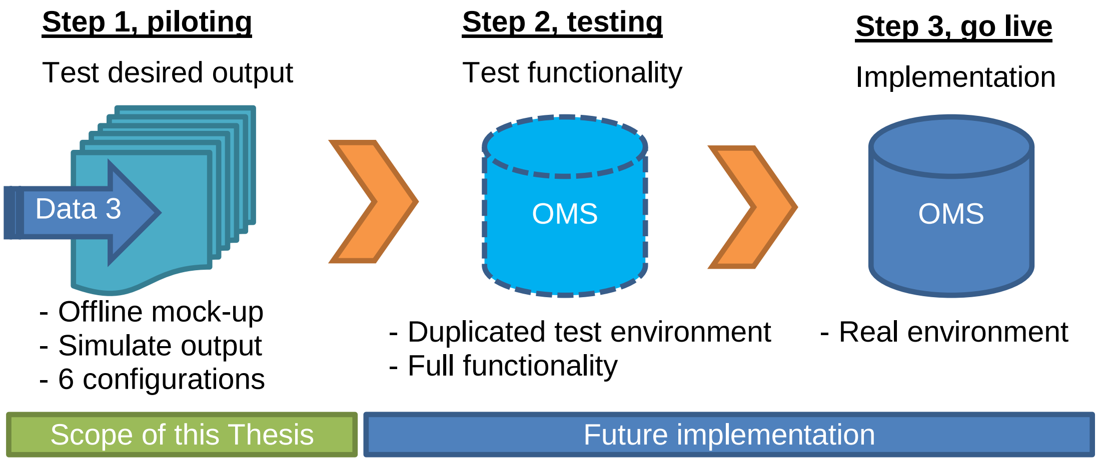

Figure 16. Validation of the proposal divided in three steps.

First, the Proposal is piloted in offline environment in Step 1. The intention of Step 1 is to test the desired output in simple way with a quick mock-up so that the fine-tuning of the Proposal is fast. The piloting was performed with six various product configurations, which were extracted from the product configurator during CSA. The Proposal draft was first piloted in offline environment in order to provide an overview of the desired output without the need to put attention in possible system compatibility issues yet. The visualization of the output is simulated as it would be extracted from the product configurator. The scope of this Thesis work includes only Step 1, therefore the Data 3 is collected and implemented within Step 1.

Second, the Proposal is placed into a test environment in Step 2. This Step 2 is already out of scope for this Thesis. The refined Proposal, which is the updated Configurator output generator, is uploaded to a test environment. The test environment is an exact replica of the production environment. Therefore, in case of any unpredicted issues, the production environment is not affected. This step focuses on detecting possible system issues such as invalid configuration rules, corrupted data or missing programming logic.

Finally, the Proposal is implemented in live environment in Step 3. After the previous steps are successfully completed and Proposal refined accordingly, the Proposal may be implemented to the active production environment. This summarizes the overview of the validation of the Proposal. Next, the findings of Data 3 collection are discussed.

6.2 Findings of Data 3 Collection

The Data 3 consisted of two types of feedback. First, the findings from the piloting, which was the validation Step 1. Second, the suggestions from the key stakeholder were collected similar way as in the previous section. Next, the findings after the piloting phase are discussed.

6.2.1 Findings of Data 3 after Validation Step 1

The piloting was performed with six predefined fully specified product configurator extracts. In practice, the output data was processed with an offline spreadsheet to visualize the requested output. Once the test configurations were processed, comparison of the existing output to the Proposal was possible. An example of the visualization and sanity check of a configuration is attached in Appendix 2.

Table 11 summarizes the findings from the Data 3 piloting. The previous configurator setup consisted of 22 different top item groups, whereas the new proposal consisted of 25 different top item groups. The item differentiation logic remained rather similar, yet the additional new groups were created in order to distinguish certain fundamental structural differences of the products.

Table 11. Summary of the piloting, Validation Step 1.

Test configuration #	**1**	**2**	**3**	**4**	**5**	**6**	**Average**
Invalid grouping	16	14	20	18	19	14	16,8
Valid grouping	43	54	51	56	64	51	53,2
Total amount of top items	59	68	71	74	83	65	70,0
Validity rate	**73 %**	**79 %**	**72 %**	**76 %**	**77 %**	**78 %**	**76 %**
Old group assignments	13	19	18	18	17	18	17,2
New group assignments	18	17	19	18	19	18	18,2
Requires detailed product knowledge	2	11	37	25	42	26	23,8
Requires detailed product knowledge	**3 %**	**16 %**	**52 %**	**34 %**	**51 %**	**40 %**	**33 %**

As seen from Table 11, the percentage of invalid top item group assignment is on average 24%. The share of invalid groupings is not changing dramatically despite the differing number of top items (from 59 up to 83). Hence, a systematic invalid grouping logic exists, which was already visible also in the results from CSA.

Furthermore, the piloting stage highlighted the issue related to misleading grouping of items. Whereas the proposed Configurator output generator defines groups with descriptions that are understandable also for external people, the old naming was misleading even for persons who know the products well. For example, now the Configurator output generator includes description “Hydraulics”, which collects all top items related to hydraulic system. Today, the corresponding existing group description is “Component group G”, which refers to old internal coding of the case company. Table 11 presents also this evaluation, which resulted for test configurations 3 and 5 more than 50% of arbitrary descriptions.

Next, the findings after the piloting are summarized. First, the validity rating presented here was rather subjective evaluation as some evaluated top items were into some extent valid. However, the absolute number is irrelevant, as any invalid grouping should be corrected. Second, although the grouping of new items may be improved on average 24%, the number of all available group assignments increased only by three, from 22 group assignments to 25 group assignments. Third, regardless of the higher total number of top items, roughly the same number of group assignments are needed. High total number of top items only refers to more complex product configuration which consists of many features. Fourth, the number of old and new groups is irrelevant, especially as the old groups are misleading or invalid. Hence, the number of new group assignments only tells in how small segments the configuration is wanted to be divided. Fifth, the Proposal is not only fixing the invalid group assignments, it also internally clarifies the type of components which previously required deeper technical product knowledge.

This summarizes the findings of the Piloting stage. The Piloting confirmed the intended functionality of the Configurator output generator. The results were promising, as the developed Proposal is expected to correct the invalid group assignments. In addition, as a byproduct, the Proposal is expected to bring internal transparency since the top item groups may be identified even with limited technical skills and modest amount of product knowledge. Next, the suggestions from the key stakeholder are discussed.

6.2.2 Findings of Data 3 Key Stakeholder Suggestions

To validate the proposal, the study involved the key stakeholders for feedback and evaluation (Data 3) of the proposal. Data 3 consisted of mainly minor, yet relevant suggestions from the Configurator engineer. The suggestions are collected in Table 12.

Table 12. Key stakeholder suggestions for validation of Proposal (Data 3)

	Topic	*Suggestions from stakeholder*	*Description of the suggestion*
1	Guidelines and documentation	Summary of all available group assignments to be created.	A document or simple listing of all available group assignment is needed in order to be prepared for the maintenance of existing logic after the release.
2	Validity analysis	Validation evaluation requires further development if planned to be implemented.	The validation concept requires more work if it is intended to be implemented as there are no simple means to define whether an item has correct assignment or not.
3	Group assignment codes	Fine-tuning of certain group assignment codes is needed.	Some descriptions need to be shortened. In addition, illegal characters (“&”) notified.

This summarizes the suggestions from the key stakeholder. Next section discusses the developments to the proposal based on these findings.

6.3 Developments to the Proposal Based on Findings of Data 3 Collection

This section discusses the development of the Proposal based on the Data 3 collection. The Data 3 was twofold, hence the finalization of the Proposal is divided into two parts. First, the development based on findings after the Piloting are discussed. Second, the development based on the suggestions from the key stakeholder is discussed. Next, the development based on the findings from Proposal Piloting is discussed.

6.3.1 Development to the Proposal after Piloting

Only minor development needs after the Piloting were identified. The identified issues were the following. First, some top items which consists of components from many item categories are difficult to assign to a single available group. However, this challenge was already visible in results from CSA given the existing various structuring logics. Therefore, even if single items are not assigned with an ideal description, it will be relatively close in terms of functionality rather than invalid. Hence, minor adjustments in the groupings were performed after the Piloting.

Second, the defined descriptions for the group assignments could be further developed. However, no significant defects were detected during the piloting. Again, compared to the existing state, even rough descriptions are in some cases a significant improvement compared to misleading or invalid description.

As a conclusion, only minor adjustments were performed based on the findings after the Piloting stage. Next, the key stakeholder suggestions are discussed.

6.3.2 Development to the Proposal Based on Key Stakeholder Suggestions

The key stakeholder suggestions consisted of three points. First, the need of documentation was pointed out. The documents must be available when releasing the updates in order to secure the implementation and maintenance already from the very beginning. A brief guideline was planned to be released internally after the Thesis work. After the feedback, more comprehensive documentation will be prepared as an internal company document which is not part of this Thesis scope.

Second, the presented validity analysis was commented as a personal curiosity of the stakeholder as it is not relevant for the actual Proposal. The subjectivity of the validity evaluation was pointed out in Section 6.2.1, as it was only a tool to illustrate the changes. Such a validation tool could be used to monitor the data quality, however the development of the validation concept is not in the scope of this Thesis.

Third, fine-tuning in the defined group assignment codes were suggested. Some of the code descriptions required further shortening in order to be implemented. Also illegal characters were pointed out, which will be replaced. The validity of input would have been notified in validation Step 2, however the updates are at easiest to perform at this stage.

As a conclusion, only minor adjustments were performed based on the suggestions from the key stakeholders. Next, the final Proposal is discussed.

6.4 Final Proposal

The final Proposal was refined based on initial Proposal and embedding of Data 3. The final Proposal consists of 25 group assignments with descriptions, in which the approximately 4100 active top items were divided. Hence, the product structures extracted from the product configurator are rationalized. The rationalization was realized in terms of valid grouping of extracted top items, understandable group assignment descriptions and harmonized naming of the top item grouping.

The essential part of the Proposal is the Configurator output generator, which is illustrated in Figure 17. The Configurator output generator was defined inside the existing configurator tool. The input for the generating mechanism is a fully specified product configuration. Next, the product configuration is converted into flat list of top items, which are assigned to pre-defined groups. This output is the rationalized product structures extracted from the product configurator.

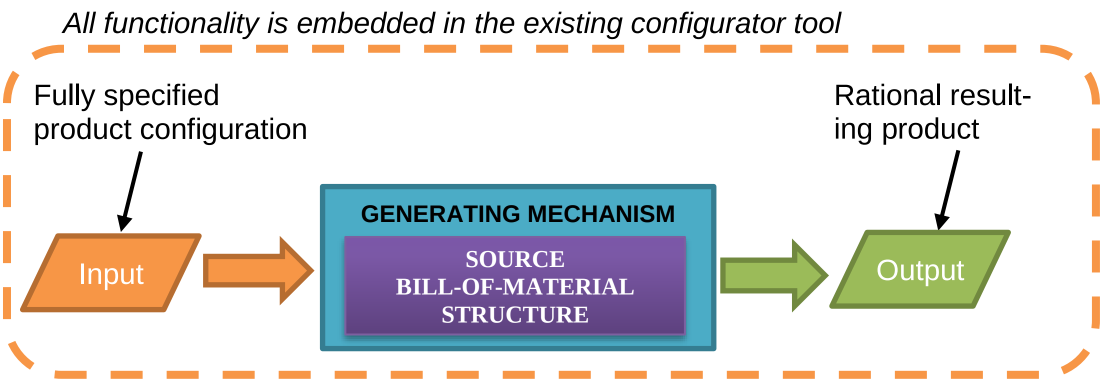

Figure 17. The Final Proposal for the Configurator output generator.

This ends the Proposal development. The Proposal is ready to be implemented in the test environment, which is the validation Step 2 discussed in Section 6.1. The validation Step 2 and Step 3 are excluded from this Thesis, as the implementation of the Configurator output generator is only related to validate the compatibility of the programming and settings of the configuration rules. The implementation of the final Proposal is expected to be simple as it, in the end, only requires redefinition of data tables according the developed logic. However, although the nature of this update is close to cosmetic update, the live functionality must be carefully reviewed. As in case of any missing or invalid configuration rule, the consequences in the production environment might be unpredictable.

6.5 Recommendations for Next Steps

The next steps are divided into two separate topics. First, recommendations toward implementation of the final Proposal are summarized. Second, recommended next steps based on the findings during this Thesis work are summarized. Next, the recommendations toward implementation of the final Proposal are discussed.

6.5.1 Recommendations toward Implementation of the Final Proposal

First of all, once the final Proposal is implemented, a wide stakeholder feedback collection is highly recommended. A suitable time after the implementation could be some months, which is a suggested to be long enough to include also very special product configurations such as non-standard product orders. Therefore, the final Proposal was created in such a way, that the modifications such as new grouping codes or updates in the existing codes is possible. Typical to any development project, the ultimate finalization of the Proposal is possible only after the organization has really implemented the new practice. Here the finalization refers more to enhancements to utilize the most of the benefits of the Proposal rather than fixing mistakes.

Second, the possible further development of system tools should be evaluated. As the Configurator output generator is rather reliable and simple addition, it could be used as input to other tools for example to monitor product costs or identify trends in order intake. As pointed out in results from CSA, several tools and systems are used to collect the same data. Perhaps, the extracted structures could be merged with other relevant data to avoid several overlapping tools. In addition, a dashboard view of the Configurator output generator data could be created to gain more detailed market and customer insight.

Finally, the developed final Proposal could be introduced to other product lines within the case company in case they are utilizing the tools in similar way, possibly facing similar challenges. As the same product configurator is applied within the case company, the Configurator output generator is expected to be implementable with very low effort. Moreover, the similar categorization of items could benefit high level sourcing activities and corporate Category managers as similar items are easy to extract and manage.

This summarizes the recommended next steps for the final Proposal. Next, the recommended next steps related to other identified opportunities during the Thesis work are briefly discussed.

6.5.2 Recommendations to Further Investigations

This section summarizes the opportunities which were identified during this Thesis work. The identified opportunities were not part of the scope of this Thesis, yet they are still important for the case company.

First of all, although the obvious solution to secure reliable output data would be to fix the input data, it would not solve the issues today. In this context, it would take a long time until the product configurations consist of only new items. For example, even today items designed in 1970’s are still in the active production. Given this, the time to update each item in natural development is expected to take a long time. Nevertheless, the found issues related to data input quality will be conducted to Design department for further evaluation.

Second, the grouping of extracted items supports the overall management of the products. Once the product data is settled in a clear way, it may be utilized further in detailed cost analyses, for instance. There are various possible reasons for the high costs, hence further root cause analysis is needed as the identified high costs might be hidden in the supply chains. The identified issues related to misaligned item costs will be conducted to Sourcing department for further actions.

Third, the introduced way of reprocessing the top items could be utilized as baseline for new design projects and benchmark. One expected benefit is the evaluation of required number of new top items, as by more transparent structuring the early estimations could be done in more accurate manner. Another benefit highlights the differences between features and product types, which could be clearly introduced to external stakeholders in very early development stages. Furthermore, the increased transparency after implementation of the Proposal might bring further additional benefits which should be reviewed.

Summing up, this section discussed the validation of the Proposal. Only minor adjustments were required after analyzing Data 3 which consisted of the findings after piloting of the Proposal, as well as suggestions from the key stakeholder. Furthermore, the final Proposal for the Configurator output generator was introduced. Finally, the recommendations for next steps were given.

Next, conclusions of this Thesis are discussed.

7 Conclusions

This section summarizes the conclusions of this Thesis and interprets the results. First, an executive summary is given. Second, managerial implications are summarized. Finally, the Thesis is evaluated, after which closing words end this Thesis.

7.1 Executive Summary

The objective of this Thesis is to *rationalize product structures extracted from the product configurator*. Global goods manufacturing companies are expected to deliver product variants satisfying varying needs in several customer and market segments. Therefore, product configurators are applied to offer customer-specific products composed of interchangeable components. The output of the configurator is a listing of product structures, which act as a receipt of the selected configuration. The selected business problem was related to product structures extracted from the product configurator which were difficult to compare. This Thesis proposes a solution for the problem.

This Thesis analyzed the results from CSA of a product configuration output in the case company which resulted in a list of identified strengths and weaknesses. The identified main weakness was the difficulty to compare product structures extracted from the product configurator. The study then searched for best practice related to the topic from literature. Based on the literature review, a conceptual framework was built consisting of configurable product offering, product structure management and configurator output. Furthermore, the initial proposal was built by pulling together the results from CSA, CFW and suggestions from the key stakeholders.

The proposal contained a Configurator output generator which was modified according the findings from CSA, CFW and embedding the feedback from key stakeholders. The Configurator output generator is an integrated part of the existing product configurator tool, which restructures the fully specified product configuration input. By relabeling the item group assignments and redefining the descriptions, the visualization of the extracted product structures was significantly improved. In addition, the modifications may be implemented with very low effort by simply relabeling the output of the existing configurator. Hence, the input data and critical design data remain as-is, which minimizes the risk of disturbances in the existing production flow.

The results already after the initial Proposal were promising. The comparison of different configurations was easy as the structuring logic is comparable and easier to understand. The number of invalid item assignments can be significantly reduced, and simple analysis of the product does not require anymore very detailed technical knowledge. Hence, the comparisons are expected to be easier to perform and therefore less product training and support to sales units and new employees is required. Furthermore, the transparency between products and product features is improved. Comparison of different features is easier and faster, as the resulting items are clearly visible for all persons who have access to the product configurator.

In addition, several internal benefits for the company were identified. First of all, the product costs are easier to monitor and compare. Similar items may be grouped to identify item costs which are misaligned. Second, the extracted structures can be used as baseline and comparison for new product development. The rationalized product structures support to compare the functionality, estimate number of new items and share of different top item types of the existing products. Finally, the input of new data can be prepared according the Proposal which improves eventually the coherence of the product structures and unifies the structuring logic.

The final Proposal was successfully piloted in an offline environment. Regardless of the fact that the group assignments are changed in the very end of the product configuration process, number of existing or old connections to ERP systems might exist due to the long history and scattered global sites of the case company. Therefore, the actual implementation to live environment requires thorough validation and a suitable time slot to update the configuration rules in one go. Hence, the results of final implementation are not included in this Thesis.

After the implementation, the rationalized product structures extracted from the product configurator are expected to minimize complexity both internally and towards the customers. In addition, the transparency and level of utilization of the configurator tool is expected to be increased. Furthermore, the time to compare product structures in terms of design and cost is reduced.

7.2 Managerial Implications

For the case company, only the last step for the implementation is required. In practice the required time is estimated to be from some hours to a couple of days in order to assign the Configurator engineer to review and approve the final Proposal. After the Proposal is implemented, part of the estimated benefits are to be utilized immediately.

As most of the systems and processes are already in place, the next actions are related to realize the full potential of the rationalized product structures.

First of all, as the tools are internal, the maintenance costs are estimated to be low or non-existing. It turned out during the CSA that the configurator tool is rather poorly utilized, regardless of the fact that it is a rather powerful tool as it contains a lot of relevant product information. Therefore, increased utilization of the tool is advised which could be reached by trainings and internal promotion. The basic problem seemed to be that not many employees even knew of the existing tool and its features.

Second, many projects and change tasks could be started by reviewing the product configurations which are subjected to changes. The rough number of items, complexity and target costs could be estimated with a glance instead of very thorough estimations during the scoping phase. For high level project initiation and business case purposes the resolution is fair enough.

Third, the harmonized and rationalized output of the configurator also simplifies drawing conclusions from the statistics. The data of delivered configurations is of course the same, yet after implementing the Configurator output generator the conclusions are more tangible. For example, the share or number of high-end products is easier to distinguish based on the level of certain component groups.

Finally, in order to gain even more benefits, further post-processing of the output data is advised. The total product cost can be now easily segmented which provides transparency in controlling the costs. For example simple and fast way to extract share of hydraulic components may be used for various purposes and evaluations.

7.3 Trustworthiness of the Study

The initial objective of this Thesis was to rationalize product structures extracted from the product configurator. The objective was selected to solve an existing business challenge and identified main weakness *product structures extracted from the configurator are difficult to compare*. The outcome of this Thesis fulfills the objective and solves the business challenge. The Proposal delivers means to rationalize product structures extracted from the product configurator. Therefore, the delivered outcome of this Thesis is in-line with the objective and the initial problem is solved.

Next, the findings during the research process, its limitations and suggestions what might have been done better are discussed. Then, evaluation of the four criteria of trustworthiness is discussed.

7.3.1 Thesis Evaluation

The main challenge during the research process was the level of engagement from the case company due to other important business tasks. As most of the activities and resources are preliminary planned beforehand, the required resources for this Thesis were challenging to evaluate in the beginning. Hence, the practicalities such as workshops were occasionally difficult to agree as the informants had other prioritized tasks at the same time. This could have been avoided by creating a small research tasks or a project in order to emphasize the estimated business benefits to gain the attention.

Furthermore, although all relevant meetings and workshops were documented, most of the discussions and progress was done in numerous small iteration steps and during ad-hoc meetings. As the study aimed to solve a business problem, the most relevant and interesting outcome for the case company is that the problem is solved and the risk of renewal is mitigated. However, the dependability of the qualitative research is lower if all short ad-hoc discussions are not documented, or if some of the phenomenon was notified during the research due to fortunate coincidences. Even though this is presumably typical challenge to Design research which takes place in business organization context. Some sort of a discussion log file or diary including minor findings could provide more thorough transparency and improve the dependability of the research.

Finally, regardless of the fact that the Thesis scope was limited in such a way that direct dependencies to different persons and departments were minimized, challenges existed to fit the schedules for meetings and discussions with the key stakeholders. Although most of the preparation could be done individually, at the final stages the testing and implementation required very deep knowledge of product management, configurator tool and system architecture. Hence, several experts were needed during the study.

What worked well during the research was the amount of found best practice from the literature. Despite the fact that the research topic was very specific and highly context related, many companies seem to face challenges in the same areas of the business. Regardless of the uniqueness of the research problem in this Thesis, several applicable good quality research articles were found. Another success was the high level of motivation and engagement of the key stakeholder, the Configurator engineer. The willingness to develop the tool and seek for improvements supported the progress of this research.

An alternative approach or more sophisticated methods could have been incorporated in the developed mechanism to restructure the extracted product structures. However, once the created Proposal is implemented, further development and fine-tuning of the proposal is expected to be easy. This was the intention already from the beginning, due to two reasons. First, some of the items are difficult to assign to specific group as they consists of components from many groups. Second, the Proposal must be adapted to future items which are not existing today. Hence, it was more important to provide a decent and functional mechanism to restructure the extracted product structures rather than aim for perfect grouping logic by knowing that the logic is subjected to changes over time.

This summarized the reflections of the research process. Next, the evaluation criteria from Section 2.4 are re-evaluated after the research was conducted.

7.3.2 Credibility

Credibility evaluates the extent to which the findings of the qualitative research make sense. The measures of credibility are adapted from Shenton (2004). Below in Table 13 is presented only updated part compared to 0.

Table 13. Measures of credibility and updated applicability in this research.

Measures of credibility	**Updated applicability in this research**
Adoption of appropriate, well recognized research methods.	The intention was to apply semi-structured interviews throughout the research. However, only the initial interviews and discussions were semi-structured, after which they turned into unstructured interviews and open discussions.
Debriefing sessions between researcher and superiors.	Due to organizational changes the debriefing was performed mainly in the beginning and in the end of the research.
Peer scrutiny of project.	The progress of development was updated occasionally and on a need-to-know basis.

7.3.3 Transferability

The methodology and process is transferrable to other contexts as well. The approach and the developed Configurator output generator could be used as such, however the practical implementation depends heavily on the flexibility or the in-built functionality of the existing product configurator tool. Yet arguably many goods-manufacturing global companies have applied very similar tools. Hence, the developed solution is at least partly, if not fully implementable in other contexts as well. Below in Table 14 is presented only updated part compared to 2.4.2.

Table 14. Measures of transferability and updated applicability in this research.

Measures of transferability	**Updated applicability in this research**
The number of participants involved in the fieldwork.	All relevant key stakeholders were involved, which ended up to result in Product manager and Configurator engineer which were the only active participants of the research.
The data collection methods that were employed.	The initial interviews were semi-structured, however most of the numerous short interviews were unstructured both face to face and conference calls. Workshop-type discussion was arranged during Data 2. Data 3 feedback was delivered in written format via e-mail.
The number and length of the data collection sessions.	A kick-off 2h workshop conference call was conducted. Four 1h conference calls were conducted with the Configurator engineer. In addition, numerous shorter calls, e-mails and ad-hoc meetings during CSA and proposal building were conducted.
The time period over which the data was collected.	Data was collected in January 2019 for CSA, March 2019 for Data 2 and April 2019 for Data 3.

7.3.4 Dependability

The conducted study would most probably end up in very similar result if repeated, due to the limited flexibility of the configurator tool. However, the detailed proposal would be different, as the assignment and naming of item group was subjective in nature. Hence, details might have changed, yet the logic would remain very similar. Therefore, no updates occurred related to the applicability of the research.

7.3.5 Confirmability

Confirmability in the qualitative research evaluates the objectivity of the researcher and assures the findings originate only from the informants. An update, or a remark was related to poor internal utilization of the configurator tool. Although it is an important finding as-such, the number of co-innovation participants in practice narrowed down in the end to the researcher and Configurator engineer. The number of participants does not necessarily reflect to the quality of results, however there is a risk that all the relevant aspects are not considered to gain maximal benefits of this study and utilization of the existing tools. Hence, additional workshops with wider audience could have been arranged to find out how to possibly take more advantage of the product configurator instead of focusing to specific solution oriented discussion.

7.4 Closing Words

As this Thesis showed, the rationalization of product configurator output does not required revolutionary technical development. Instead, it requires understanding of the desired and relevant output. Rather small adjustment in existing product configuration process is expected to improve transparency, product knowledge and eventually bring business benefits for the case company. In addition, this Thesis challenged the key stakeholders to consider also other participants to enhance the cross-functional cooperation as well as encouraged the case company to utilize more the existing configurator tool.

After the case company reaches a good command of basic functionality of configured products, the following development steps could increase the customer intimacy and operational excellence in the area of order management. This in turn is expected to result in significant differentiation from the other manufacturers, hence offering a competitive advantage. Proven product expertise combined with a transparent, configurable and easy to understand offering is a combination which forms a business card hard to beat.

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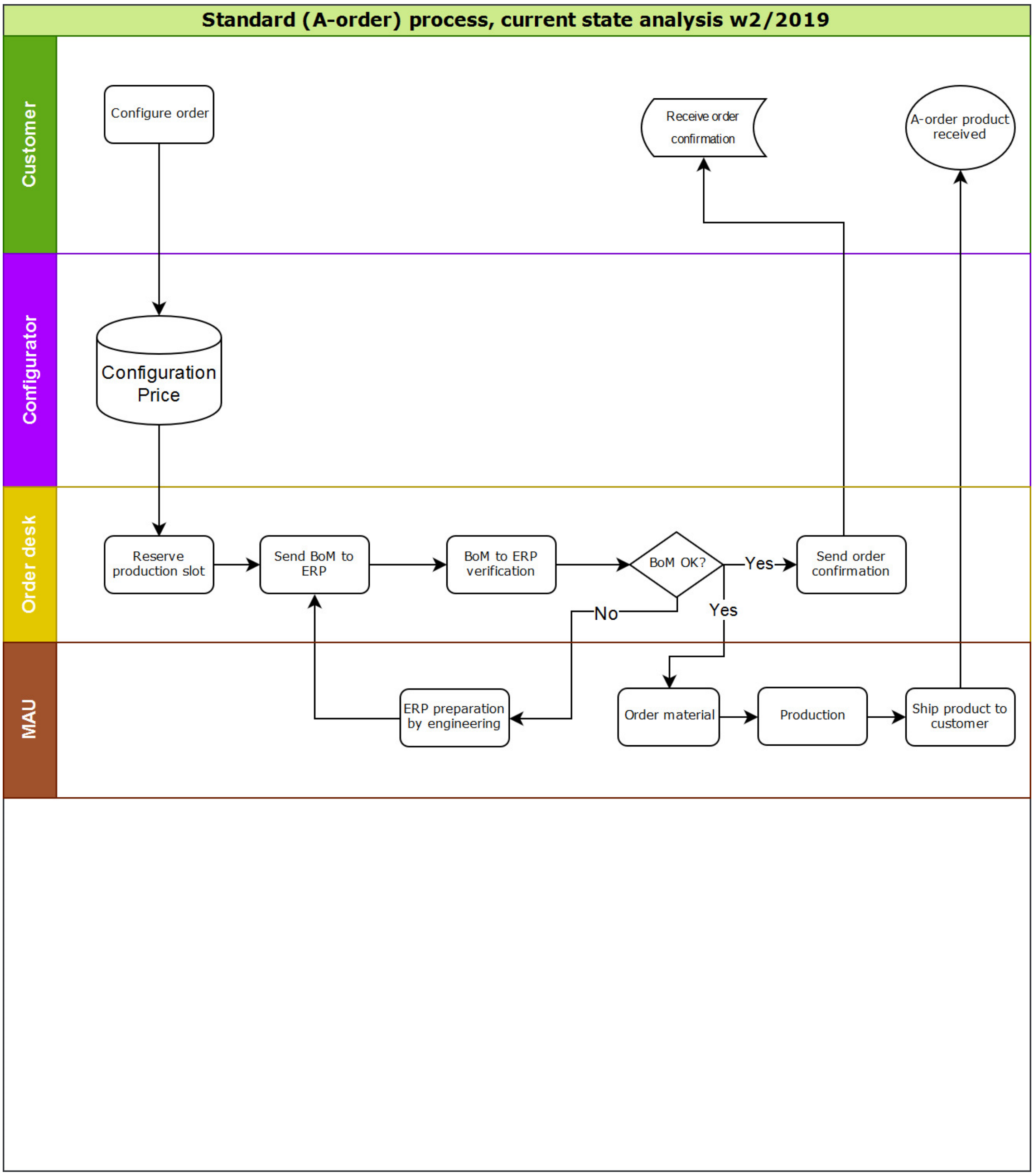
Appendix 1 Standard Order Process Flowchart

Current state analysis of a standard order process is illustrated below. Abbreviations used: Bill of Material (BoM), Enterprise Resource Planning (ERP), Multi Assembly Unit (MAU) which equals to production unit.



Appendix 2 Example of Validation Step 1, Configuration 1

Example of validation Step 1 for configuration 1. The Family identification codes are on purpose unrecognizable. Colors illustrate the type of the items, which are compared to define whether the original family code was valid or not.

#	Family	New Family	Article #	Valid?
1	[illegible]	[illegible]	4566431	✗
2	[illegible]	[illegible]	91173002	✗
3	[illegible]	[illegible]	93042002	✓
4	[illegible]	[illegible]	93042101	✓
5	[illegible]	[illegible]	4556512	✓
6	[illegible]	[illegible]	4551157	✓
7	[illegible]	[illegible]	112500	✓
8	[illegible]	[illegible]	304956	✓
9	[illegible]	[illegible]	91153401	✓
10	[illegible]	[illegible]	112801	✓
11	[illegible]	[illegible]	4562797	✓
12	[illegible]	[illegible]	212291	✓
13	[illegible]	[illegible]	212302	✓
14	[illegible]	[illegible]	304008	✓
15	[illegible]	[illegible]	7371794	✓
16	[illegible]	[illegible]	212499	✓
17	[illegible]	[illegible]	4567654	✓
18	[illegible]	[illegible]	7356668	✓
19	[illegible]	[illegible]	91107201	✗
20	[illegible]	[illegible]	93047311	✗
21	[illegible]	[illegible]	94552531	✗
22	[illegible]	[illegible]	3870495	✓
23	[illegible]	[illegible]	4564193	✗
24	[illegible]	[illegible]	3870486	✓
25	[illegible]	[illegible]	93047042	✗
26	[illegible]	[illegible]	91105811	✗
27	[illegible]	[illegible]	91172211	✓
28	[illegible]	[illegible]	118003	✓
29	[illegible]	[illegible]	3361161	✓
30	[illegible]	[illegible]	1948458	✓
31	[illegible]	[illegible]	8553718	✓
32	[illegible]	[illegible]	212318	✓
33	[illegible]	[illegible]	212316	✓
34	[illegible]	[illegible]	4547482	✗
35	[illegible]	[illegible]	4557708	✓
36	[illegible]	[illegible]	4569827	✓
37	[illegible]	[illegible]	4547074	✓
38	[illegible]	[illegible]	4556514	✓
39	[illegible]	[illegible]	4569828	✓
40	[illegible]	[illegible]	212699	✓
41	[illegible]	[illegible]	4556613	✓
42	[illegible]	[illegible]	4548176	✗
43	[illegible]	[illegible]	4548177	✓
44	[illegible]	[illegible]	93047281	✗
45	[illegible]	[illegible]	4556508	✓
46	[illegible]	[illegible]	93045002	✓
47	[illegible]	[illegible]	3313760	✓
48	[illegible]	[illegible]	3313751	✓
49	[illegible]	[illegible]	211478	✓
50	[illegible]	[illegible]	91172671	✗
51	[illegible]	[illegible]	93043902	✗
52	[illegible]	[illegible]	93042651	✗
53	[illegible]	[illegible]	4556518	✗
54	[illegible]	[illegible]	91179101	✓
55	[illegible]	[illegible]	91178821	✓
56	[illegible]	[illegible]	91172502	✓
57	[illegible]	[illegible]	91171911	✗
58	[illegible]	[illegible]	4554744	✓
59	[illegible]	[illegible]	93044253	✓