Commercial and Technical Productization for Design Reuse in Engineer-to-Order Business

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***Abstract*—In the engineer-to-order (ETO) business, companies provide customer value by customizing the products according to the customers' needs in a project-like manner. As a result, the number of individual product designs tends to proliferate, causing challenges in company operations, and product portfolio and product lifecycle management. In addition, if the company's product offering is not well productized, using the ETO model may further lead to poor understanding of the offering, deficient reuse of previous designs, and challenges in sales and making offers. A qualitative multiple case study was conducted to analyze the productization challenges of four ETO companies. On the basis of the challenges and the previous literature, a generic model for commercial and technical productization in ETO business was constructed and further tested in the companies. The model utilizes the logic of commercial and technical product structures. The product structure logic is linked to four different scales of product development processes to address different types of customer requests based on the complexity of the modification that the request necessitates. The model may support clarifying the product offerings of ETO companies to improve their design reuse, sales, and making offers. Further, the ETO order-related decision-making can be linked to product portfolio management targets and company strategy.**

***Index Terms*—Design reuse, engineer-to-order (ETO), product structure, productization.**

I. Introduction

OFFERING customer-specific products is a way for engineer-to-order (ETO) companies to meet various customer needs and thus create more customer value. Customization may be a competitive advantage in some markets, but in others, it is more of an enabler to stay in business than a competitive advantage [1]. As customization has become a norm in some competitive markets, companies need to compete with other factors, such as delivery time and price [2], [3].

Attempts to meet various customer needs by customization may easily lead to a quick increase in the number of individual product designs [4] followed by new parts, bills of materials, and production routings [1]. This makes reliable product delivery difficult, as production lead times and delivery estimates should be known already in the contract negotiation phase [2]. A challenge with large product variety is to ensure the correctness of product information without too many costs [5]. Profitability may vary greatly between different products, and if the product variety keeps growing, the overall profitability of the product portfolio may decrease and even become negative [6]. Due to the price competition, companies should simultaneously seek cost reductions, to which the reuse of designs and the standardization of assemblies and components may provide a means [2]. However, reusing the previous designs can be challenging if companies do not have suitable mechanisms for that [7]. To succeed in the reuse, information that is stored in information technology (IT) applications must be complemented with the employees' knowledge [8], as design reuse is often dependent on the designer's experience and knowledge of the previous designs [9], [10]. ETO companies cannot rely on standard solutions only, but certain engineering is necessary [11] along with a controlled balance between standard and engineered. The lack of a generic product model impedes effective reuse [12] and may cause trouble in invoicing. The cost estimation and price setting of an ETO product include a higher risk and uncertainty compared to standard products as the product's final specification may change and the product may prove more difficult to produce than expected [3], [13]. In addition, creating new variants affects not only the new product development (NPD) and production but also the after-sales services as repair and spare part capabilities need to exist to cover product warranty [14]. This may include product redesign due to obsolete components [15].

A uniform, company-wide view of the products is needed to know what can be offered and delivered. It is vital to understand and keep track of product and process changes [16]. In the case of ETO products, it is important to know what parts of the product can be customized [13]. To achieve a uniform view of the products, companies can productize their offering. Productization consists of activities that make an abstract offering more concrete so that it is easier for the employees and customers to understand and more efficient to produce [17], [18]. Productizing the product portfolio with a generic product structure that acknowledges the commercial and technical aspects of the products provides a way to gain the needed understanding [19]. The systematic modeling of products enables calculating their profitability [5], [20]. The previous literature has not considered productization for ETO products.

Generally, the current considerations of productization in the light of commercial and technical product structures [19], [20] are most applicable in the case of standard products and services. ETO types of products have not been studied. This even if

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product modeling and knowledge acquisition are considered among the most important related challenges [21]. Some models (for example, see [12]) have been proposed to improve design reuse for cost reductions and shorter lead times in ETO business. The current models, however, do not link productization to how different types of design change requests should be considered. Requests of different types may need separate development processes [22]. The focus of productization in ETO business should be extended from design reuse to improving uniform, company-wide understanding of what can be offered to the customers. Appropriate understanding may enable more accurate product-level profitability estimates for reducing the risk in negotiations and tendering. An item-based approach with consistent product structure levels needs to be linked to the processes of how to deal with different types of design change requests.

This study aims to improve the productization practices of ETO companies to enhance their negotiations and tendering. Here, productization is considered as the process of defining the product offering to make it understandable and communicable to all stakeholders. Productization answers the questions of what the commercial offering is and how it is realized technically. A well-productized offering, including the products and all their variations, is easy to offer, sell, deliver, invoice, and develop further.

The study investigates four ETO companies to reveal the challenges they have related to productization and product structures. Further, a generic model for commercial and technical productization is developed for ETO products and linked to four product development processes of different scales. The study is approached through two research questions (RQs) as follows.

1) *RQ1:* How do productization-related challenges hinder negotiations and tendering in ETO companies?
2) *RQ2:* How can productization through the commercial and technical product structures be utilized to improve negotiations and tendering in the ETO business?

The rest of this article is organized as follows. First, Section II presents the literature review on productization, the related challenges, and product structures in ETO business. Relevant productization-related viewpoints are identified to provide links between negotiations, tendering, and productization due to deficient coverage by earlier ETO research. The literature review provides a basis for the empirical data collection and the development of the productization model for ETO business. Section III describes the research process and the applied methodology. Section IV describes the current productization-related challenges and presents the developed productization model for ETO business. Section V discusses the meaning and importance of the findings through a dialogue with the current literature. Finally, Section VI concludes this article.

II. Literature Review

In an ETO supply chain, the design, manufacturing, and assembly of the product are conducted after the order has been placed [3], and each order is managed as a project [23]. In some products, parts of the product may be fixed but some can be customizable [24]. As the production volume in ETO business can be as low as one or a few units per order and the customer requirements may vary and be specific, the costs need to be emphasized already in the design stage [25]. The reuse of previous product designs and standardizing is important not only to reduce costs [2] but also the design lead time [26].

A. Productization-Related Challenges in ETO Business

Providing customization may lead to a vast number of unique part numbers, bills of materials, and production routings [1]. Inability to reuse previous designs may lead to inefficient performance [7]. To improve efficiency, new orders should be approached by looking for a similar, previous order and applying its design to the new one [12]. The problem is, however, that as such this would lead to the growth of single variant structures. Moreover, managing individual product variants' structures separately poses challenges in data management [13]. Many times, the success of reuse is dependent upon the designer's knowledge and experience of the previous designs [7], [9]. In addition, the sales need to transform the customer requirements into specifications and communicate them to other functional areas of the company [27]. It may be that most of the customer needs could be met by a few basic product variations [13].

There may not be clear rules about what parts can be modified and what needs to remain untouched [13]. The knowledge gap between customer interface and designers is a challenge [28]. If the customer cannot be communicated about the product and its attributes, a lot of time may be spent to carry out unnecessary work, which is away from more important tasks, such as developing new product families or improving old ones [4]. Lack of clear rules leads to sales personnel copying previous designs which may not fulfil the original customer needs [13].

In addition to avoiding unnecessary repeat work, reusing previous designs has an important role in calculating the profitability of new products. According to Sievänen *et al.* [6], broadening the existing product lines is more profitable than introducing completely new products. However, this is contrary to studies by Cooper *et al.* [29] and Barczak *et al.* [30] that suggest that developing completely new products are linked to high business performance. Simultaneously, understanding the profitability of products seems to be difficult [20]. Knowing the profitability is important, as even one-third of the products can be unprofitable [6]. On the other hand, it may be acceptable to sell a customized product unprofitably if standard products keep the entire order profitable [31]. Estimating the cost of a new design is risky since the new product may turn out to be more challenging to produce than expected, and the cost of design and engineering may not be allocated to the products but are seen as overhead costs [3].

Part of the problem is the lack of a product model that works as a structure for data, which hinders the coordination of design reuse [12]. Having a practical model for describing products has an important role in defining the product and its structure to calculate the costs of the product [5]. Lack of clear product descriptions may cause misunderstandings between the sales and the customer about the product, leading to incorrect cost

estimates and wrong pricing [13], not to mention the differences between the language used by the company and the customer to describe the product [4]. The challenge is how to maintain correct product data without reducing the product variety or increasing the management costs too much [5].

Literature finding: It is implicated that poor understanding of the offering may lead to the inability to reuse previous designs, which further leads to the growth of single structures and unclear offering.

B. Product Structure and Productization in ETO Business

A problem with productization in ETO business is that products and their order delivery are often seen as individual NPD projects, each having its separate cross-functional project team [25]. Thus, new customer-specific product deliveries are "prototypes." Another view could be to see the ETO products more as configurable products and their order delivery as a repeatable process. Certain automatization and standardization of work requiring knowledge and involving product structure can benefit also ETO companies [32]. Product design could be seen as a standardized, well-designed part of the order-delivery process. This necessitates a comprehensive understanding of the company's offering to enable design reuse [12], which can be gained by productizing the offering with a consistent product structure [17].

A generic product structure can help in preventing the uncontrolled growth of single product structures resulting from offering a large number of product variants [33]. A generic product structure includes all the possible product configurations in a single structure [34]. Thus, there is no need to create a structure for every possible product variant. Using a systematic product structure unifies and helps in product realization as different functions have varying views on the product structure and use it differently [35]. Product design creates the master structure which is used as a basis for creating product structures for other functions [36]. For example, the sales function has the view on the commercial part and manufacturing considers the technical structure [35]. The upper part of the product structure, the commercial structure, contains the elements needed to configure the product according to customer order, while the lower part, the technical structure, consists of the parts needed to manufacture the product [36]. There should be a clear linkage between the commercial structure and the technical structure. In other words, each commercial feature that the customer can buy, a sales item, should have an equivalent version item in the technical structure [19]. By referring to the sales items and version items, a consistent understanding of the products can be maintained between different stakeholders even if they have different views on the product structure. However, the traditional generic product structure assumes that all the possible configurable elements have already been defined. As such, it is unsuitable in cases where a new design is needed. Also, in ETO companies, sales and engineering configurations are too often focused on separately [37]. Nevertheless, some studies do consider the alignment of sales and technical perspectives [38].

Literature finding: A generic product structure that acknowledges the commercial and the technical side of an offering may help in clarifying the offering and preventing the growth of single structures. However, traditionally these structures do not consider ETO products.

To advance the design reuse, Brière-Côté *et al.* [12] propose a structure in which the product's common features and reused variant features are selected first, after which the customer-specific, new features are designed and added to the structure. The structure is proposed to improve the new product's cost and lead time estimations as the cost and lead time of product features that already exist are known from previous deliveries. Further, they describe an order-delivery process for ETO products. Unfortunately, the model [12] does not make a distinction between different types of product design changes, for example, the complexity or risk of product modification. As the customer need-based design changes may vary from rather minor to major, companies should have different processes for the proposed changes [22].

Literature finding: Current generic product structures for ETO products do not consider different types of product design changes.

By linking the different types of changes to the product structure, a suitable process can be addressed to the change request before starting the development [22]. Development projects of different complexity or risk can be managed, for example, through large, medium, and small stage-gate processes [39]. Analyzing the need for a relevant process is important as the new product may have its market feasibility, technical feasibility, strategic feasibility, and financial performance [40]. When creating a new design based on the customer's needs, it is also important to decide on whether the design is for the single customer only or intended to be added to the company's current product offering [31]. When adding new products, the company's product portfolio should remain its strategic fit, maximized value, and balance [41].

C. Literature Synthesis

ETO products are characterized by their early customer order decoupling point: Some parts of the products are fixed but some are to be designed according to customers' wishes. The customer orientation of ETO business tends to lead to the proliferation of unique designs, which hinders the understanding of what can be offered to the customer and how to realize it by reusing previous designs. The poor understanding makes product profitability and lead time estimating difficult, which causes challenges in negotiations and tendering. In addition, it may be difficult to know which designs form the company's "standard" offering and which are customer-specific designs. This indicates the lack of productization—a process that would clearly define and communicate what the company's product offering consists of. Productizing an ETO company's offering with a consistent product structure that acknowledges the commercial and the technical side of the offering might help the design reuse and hence negotiations and tendering. However, productization should consider the special characteristic of ETO

business, which is that the extent of the wanted design changes varies between different ETO orders. The earlier research has not met this aspect. A productization model for ETO products that would take this into account is needed to be developed. To do this, the current challenges of ETO companies need to be investigated from the productization viewpoint.

III. Research Process and Methods

An inductive qualitative method was applied in this study. Earlier research on ETO business, productization, and product structures were studied by conducting a literature review. The prior understanding of productization practices and deficiencies of existing research and related ETO challenges were synthesized to allow focusing the empirical study. The research focus was attempted to consider carefully to assist in identifying cases and aid in designing suitable research protocols. The empirical part of the study involved a multiple case study [42]. Multiple cases allow more robust theory development through replication [43].

A. Case Company Selection

The population of suitable companies in Finland was first identified by considering what type of cases would be needed to best uncover the studied phenomena and set boundaries for possibilities [44]. The companies were expected to be headquartered in Finland to allow better possibilities for access.

The literal replication strategy [45] was followed in the case selection. Sample of cases was built by setting clear criteria to aim for cases that would enable predictably similar results, providing a robust basis for developing a model generalizable to an adequate degree. However, some variation was sought by selecting the case companies from different industries with different types of products to strengthen the replication by broadening the representativeness of the sample. To be selected for the study, the companies had to employ an ETO type of strategy and product assembly and most of the companies' own-design component manufacturing had to be performed in-house. The criteria for the degree of customization of the companies' products in case of a usual ETO customer order were set to range from low–mid to mid–high: New customer orders had to require engineering work and some modification to the existing manufacturing process. This meant that companies who offered products that were customized at the point-of-delivery were excluded. On the other hand, the companies' products had to consist of some predesigned platforms or modules. This meant that companies whose business was based on creating products from scratch were excluded. The case selection was influenced by the possibilities of gaining access.

The current state analysis took place in four companies to analyze their productization practices and the related challenges. The number of the case companies should be appropriate for obtaining enough empirical evidence [46]. The depth of observation is typically better with few companies, but the number should be enough to ensure a degree of generalization and to avoid misjudging and exaggerating the data [47]. The chosen number of cases should meet these criteria.

Company A's products are integrated heating, ventilation, and air conditioning (HVAC) systems. The company's customers are businesses. The systems are highly customized according to the requirements of the property where the system is to be installed. There are some basic modules and parts that are common in every customer-specific system. However, there is no defined standard product platform and new modular parts need to be designed or supplied often. The company was selected as it represented an offering that has no distinct product platforms but whose products are built from common modules that can be modified.

Company B provides access control systems as standard products to the consumers, whereas business customers can have customized products. When customized, the modifications to the standard products are usually moderate: The core technologies, platforms, and modules remain the same, but the outer shell may change. Sometimes, more customizing is needed if the customer wants to have some new functions. The company was selected as it represented an offering that is based on distinct product platforms.

Company C manufactures production equipment for electronics businesses. Its business is highly dependent on customization, which is conducted by building customer-specific parts on standard product platforms and modules. Sometimes, the standard platforms do not meet the customer needs and a new platform needs to be created. The company was selected as it was seen to strengthen the replication logic in platform-based offerings similar to company B.

Company D manufactures power transmission systems for the marine industry. The company has several product families and numerous product variants. The company offers high customization possibilities to its customers. The products have some generic compositions, but almost any part of the products can be customized. The company was selected as it was seen to strengthen the replication logic in nonplatform-based offerings similar to company A.

B. Data Collection

The development of research instruments and protocols emphasized gaining rich data. Designing the research protocols is paid specific attention as according to Yin [48], the validity of case research data will be enhanced this way. Semistructured interviews [49] were used as the main source of empirical data in the current state analysis. Also, other data sources were utilized to enable triangulation.

The interview questionnaire (Appendix 1) consisted of questions related to the companies' current state and practices in productization and commercial and technical product portfolios, order-delivery process, product data management (PDM), product structure, management of product variants and versions, and NPD and project management. These are all relevant to the research focus.

The interviews were arranged with each company. The companies' websites were visited to find contact information of product/project managers, who were presumed to be close to persons that were dealing with these issues in their daily work. Further,

TABLE I
DESCRIPTION OF THE CASE COMPANIES AND THE INTERVIEWEES

Case	A	B	C	D
Revenue	10 m€	200 m€	80 m€	200 m€
Employees	45	700	100	550
Interviewees	Product manager	Product manager	Product manager	Production manager
	R&D engineer	Production manager	2 x Project manager	Project manager
	Sales manager	Production planner	R&D manager	2 x R&D engineer
		2 x Project manager	Sales manager	Sales manager
		R&D manager	Sales director	
		R&D engineer		
		Sales manager		
		Salesperson		
		Solution manager		
		Sourcing manager		

snowball sampling [50] was used to find potential interviewees from various organizational functions. The interviewees were asked to identify new interviewees from various functions to gain versatile data and ensure multiple views. The study was conducted for one product family in each company, so the scope of potential new interviewees was limited to employees working on that particular product family. New interviewees were added until saturation. The dilemma of when to stop is hence addressed twofold, when there is enough data to address the RQs and when no new perspectives arise. Before interviewing all the companies, the research protocols were piloted in one company to enable adjustments. Description of the case companies and the interviewees can be found in Table I. The same questions were presented to all interviewees, which enhanced the reliability of the data. However, the interviewees could explain the issues as entities to ensure gaining understanding. One interviewer asked the questions and made notes, while the other one observed and made notes. Having more than one interviewer making notes enhanced reliability. The notes were reviewed immediately after each interview and follow-up questions were made where necessary. The interviews were recorded when allowed to support the reliability of data.

In addition to the interviews, the companies' IT applications, internal and external documents, meetings, and observations were utilized as the secondary sources of data to achieve triangulation. The IT applications included enterprise resource planning (ERP) and PDM/product lifecycle management (PLM) systems, product configurators, and engineering and sales applications. They were utilized throughout the data collection and analysis to confirm the findings from the interviews by having a look at what kind of products the companies had, how the products were structured, and how they were seen by different stakeholders. The applications also allowed to understand the companies' current situation through views not only to static product master data (e.g., product structures, project numbers, and standard component/custom component) and dynamic product-related business data (e.g., sales data and supply chain data) but also to metadata (e.g., designer of a product/part). The role of the rest of the secondary data sources was small; they were utilized to gain a general understanding of the companies' product offerings and business.

C. Analysis and Construction

After the initial data collection, the individual cases were coded and analyzed. If clarification was needed in terms of responses, the interviewees were contacted via email. The researchers independently went through the data and transformed any identified challenges into codes. Coding involved creating categories by issues to enable identifying patterns and possible relationships. The codes were categorized according to their similarity and combined when necessary. As part of coding, relationships were established by identifying challenges interlinked by cause–effect (for example, lack of clear view over the commercial portfolio $\rightarrow$ difficult to sell the products and lack of generic product structure $\rightarrow$ increasing number of individual product designs). Then, the researchers went through each researcher's coding and categorization to ensure the consistency of the findings and to reduce researcher bias. The final codes included challenges related to the generic product structure, commercial product portfolio, link between the commercial and the technical product portfolios, and productization in general. Some minor adjustments were done and the main findings of the individual cases were summarized. Data from other used sources were linked to the categories. Incidents within each category were compared to each other to understand similarities and analyze potential differences. Patterns were searched by reading the created tables' researcher individually and comparing observations. A level of the chain of evidence was formed.

A cross-case analysis was conducted to compare the individual case analyses. The patterns identified in cases were compared to each other to gain an in-depth understanding. Any patterns across the cases enhance the generalizability [39]. The conclusions of the cross-case analysis were compared to the original individual case transcripts to ensure the correctness of the findings. In addition, the cross-case conclusions were presented to the interviewees before starting the creation of the productization model. This was to strengthen the study's internal validity by ensuring that there were no misunderstandings of the data, and to confirm the cause–effect relationships and that the interpretations represented the actual phenomena.

On the basis of the empirical and literature findings, an initial model for commercial and technical productization for ETO business was constructed, including the linkage of the product structure to the different scale product development processes.

The construction of the model started by going through the identified challenges and their root causes. Then, the model was constructed by combining proposals for overcoming different challenges based on the literature, the companies' current practices, the interviewees' suggestions, and the researchers' understanding. The initial model was reviewed and fine-tuned with the case companies, which improved the construct validity. The review included using the model to productize one example product family of each company. Minor company-specific modifications were done to apply the model to each company's context.

The final generic model for commercial and technical productization for ETO companies was constructed by combining the generalizable, noncompany-specific parts of the applied models. The validity of the final model was supported by asking the companies' representatives whether they were willing to try the final model to overcome productization challenges in their current business. As all the companies were willing to apply the model, the model passed the weak market test [51] and the usability of the generic model was replicated in each case.

In the second stage, the model was validated again by using four experts completely external to the research: An IT director with more than 20 years of experience in data management and product management; a chief development officer with more than 10 years of experience in data management and more than 10 years of experience in supply chain and project management; a senior data management consultant with more than 10 years of experience in data management and more than 5 years of experience in product development management; and a data management consultant with 3 years of experience in data management. First, the cross-case conclusions were presented to the experts to give them an overview of the identified challenges. Then, the model was presented and their feedback was asked to further confirm the usability of the model in overcoming the challenges. The experts' opinions improved the external validity of the study. Finally, the findings were compared with the existing literature and the contribution and implications were described.

IV. Results

A. Current Challenges of Productization in ETO Business

The current challenges include general challenges related to the nature of the ETO business. The understanding and definition of products vary as customization is strongly present in the case companies' business. A project manager in company C expressed the concern as follows: "Our company is customizing too much, and no one knows what we are offering." What is seen as a product by someone can be seen as a product family or system by others.

A common challenge in every case company is that the companies do not have a clear view of the commercial and technical items and the linkage between them. Lack of clear productization logic and consistent product structure also create challenges. As a result of the poor understanding of the commercial offering and the related features, it is rather difficult to market and sell the products. According to the sales manager in company D, "the customers cannot be given reasonable price estimates or even descriptions of what the product can consist of …. Our sales team tends to promise too much given our limited understanding of how the features can be realized. If the price is too low, we will make a loss; if the price is too high, we will lose the deal." Selling the products is often done based on the technical structures as the productization and product structures do not cover the commercial side of the portfolio. This way, the discussion with the customer tends to go too technical. For example, the sales may start with a discussion about the possible platform alternatives, which the customer does not have any understanding of, instead of focusing on the customer's needs and desired features first and then choosing the right platform. The product manager of company A described the problem by using the following analogy: "(as a customer,) I do not want to order a pizza if I do not know what kind of pizza I am going to get. I am not interested in the composition of the pizza dough or how the dough is kneaded. I am interested in the toppings and how the pizza tastes like …. The same applies to our customers; they usually do not want to know about specific components but what our products can do." The same interviewee continued that sometimes customers ask for offers from somewhere else because the company's salespersons have not been able to clearly describe how their products could fulfil the customers' needs. Thus, the customer's understanding of the product is limited to the salesperson's way of describing it.

Problems occur also because there is no definition of a "standard" product, a generic structure from which the customer-specific products could be engineered. This makes evaluating the product costs difficult. A related challenge is that new product designs created during ETO work are not utilized systematically. Each customer-specific product exists in the IT applications as a separate item, and new designs are not taken into use as new features. This leads to a situation in which the same feature can be engineered more than once, resulting in an increasing number of version items in IT applications. For example, when exploring company B's IT systems and applications, the PDM system stored only one, fixed structure for a specific product, but the ERP system included hundreds of different variations of the product as separate items. This way, it is difficult to know what the standard, regularly ordered features are. As the product features are not considered sellable items, it is also challenging to link the features to their respective items on the technical portfolio. When a new customer-specific order is created, designers need to go through the previous customer orders and find a design as close to the new order as possible and then start the redesign. Configuring the customer-specific product is based on the designer's own understanding and experience of the previous orders. The lack of linkage between the sellable features and the technical items leads to increased design cost and long development and lead times. Company B's R&D manager acknowledged and described the issue and how it links to the communication between the sales and the design: "A salesperson may sell features they know have been sold several times before. However, salespersons describe products by using their own (sales) language and terminology. As the features have not been considered as items (in the IT systems), designers use

a lot of time searching for a suitable design or, in the worst case, redesigning the whole product from a scratch, which leads our team to exceed our budget."

In addition, there are no clear rules or processes for productization—how products are defined over their lifecycle and whether a new design is to become a standard or a customer-specific design. This is challenging because of the large number of version items and the lack of a generic product structure. It is unclear which version items are customer-specific variants and which are standard versions. Obscured understanding between the standard products and the customer-specific variants impedes the development of platforms and common modules. Also, the distinction between customer request-driven development and company strategy-driven development may be inadequate. The interviewees from R&D in companies A, C, and D stated that they did not know if they ever had been part of developing a company strategy-driven new design. The R&D manager of company C made a clear statement of the company's current state: "To be honest, we do not have real R&D at all. Our R&D department just designs and develops new products based on customer orders. Development of totally new products and technologies is not systematic or regular." As productization is not in place, it may also be unclear which parts of the product can be customized and at what price. An issue related closely to evaluating the prices is that services are not systematically considered when engineering the products for the customers. There is no link between the physical products and the related services. ETO work and product installations, for example, are not described as service processes being part of the product. Record is not kept of the person-hours spent on designing a product, resulting in design not being possible to be considered in profitability calculations. As the understanding of the offering is poor, lead times are difficult to estimate.

B. Productization Model for ETO Business

For every product, a generic structure that includes all different variations of the product should be created. In the generic structure, the product's features should be seen as commercial sales items. Doing this would give products' "standard" versions from which to start selling and engineering the products. This helps in clarifying the commercial offering and makes selling and marketing the offering easier. For example, in company A, defining the sales items was seen to allow the selling to base on customer needs instead of platforms or other technical views. In company D, an additional level, sales item group, was added between the product level and the sales item level to help the sales better understand which parts the product consists of. When complemented with configuration rules, the sales item groups formed a configuration model that showed what parts needed to be chosen to form the product.

Every sales item should have a link to its corresponding technical version item. The version item may consist of an assembly, module, subassembly, component, or some other technical item. It may also be a piece of software or service. As a result, each variable or add-on feature of the product can be viewed separately, making the development and production of the features easier. Having a clear generic structure that consists of both the commercial and technical items enables one to calculate the costs and set the prices for different features, thus supporting profitability calculations. The link between the sales items and the version items enables different business functions, e.g., sales and manufacturing, to refer to the same products for those parts of the offering that are relevant to them. For example, the sales function is more familiar with the commercial side of the offering, while manufacturing has a focus on the technical side. A consistent product structure would also provide a backbone for data between company IT applications, such as ERP and customer relationship management. According to the experts, product structure challenges are common among ETO companies and having a generic product structure would be beneficial. They added that generic product structure models do not make that clear distinction between the commercial and the technical portfolio compared to the presented model. The presented generic product structure logic was seen as useful to avoid the reuse of poor and obsolete designs.

The overall focus of ETO business needs to change from pure project thinking to acknowledge the importance of having the products under control. Productization provides one possibility to advance the necessary product control. Customer-specific product customization as part of customer orders should no longer be thought of as individual large NPD projects. Instead, large NPD projects should be focused on developing new platforms, technologies, and engineering capabilities. The ETO work should be considered as a service process in the product portfolio and be part of the order delivery. Thus, the productization and the product structure should also include services by describing the respective service processes. Recognizing the ETO work and the related services as an integral and equal part of the offering (compared to the physical products) was challenging for a few interviewees. However, they acknowledged the importance and the potential benefits of structuring service processes. The service processes can be linked to the resources they require. This would help to calculate the resource needs of design and installation, as well as their costs which can be subsumed into the price of the physical product or invoiced separately as a service. Knowing the costs of previous similar types of ETO works helps in estimating the costs of the new design. In company B, a concern was raised that some service productization efforts might be difficult to implement due to after-sales services (maintenance and repair) and physical product selling being in separate business units. Thus, productization should be seen as a company-wide issue.

Product development can be systematized by defining clear processes for different types of product design changes (Fig. 1). According to the experts' validation, companies in different industries have this kind of processes in place. However, companies have not usually considered the processes as services and being part of the offering, though experts see they should. In the present model, when a new customer request is received, a predevelopment analysis and decision-making should be conducted. Initial analysis and decision-making on whether the new design will be added to the standard offering, or remain as a customer-specific design, should be made. The market-related, technical,

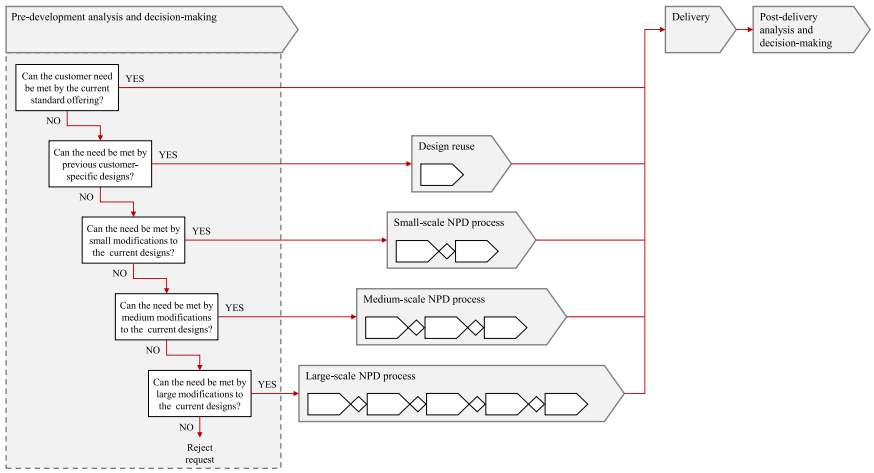

Fig. 1. Product development processes of different scales.

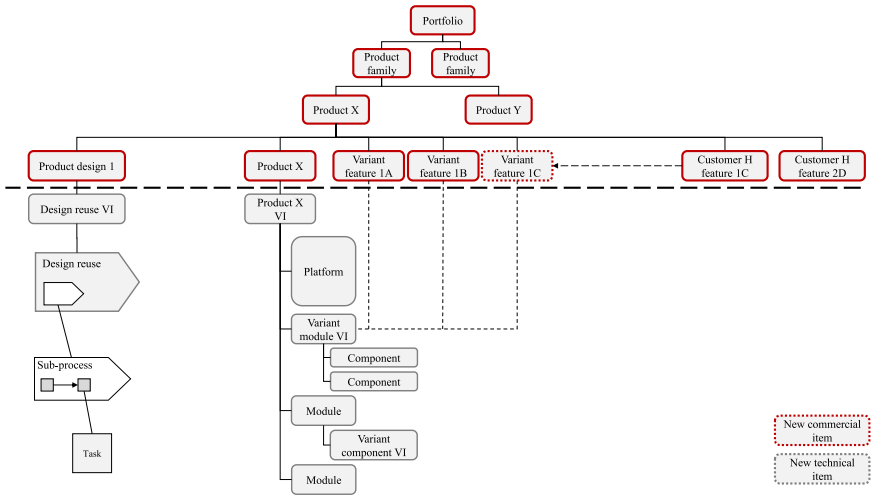

Fig. 2. Productization through the design reuse process.

and strategic feasibility, as well as the financial performance of the new design, should be considered. In addition, the company's product (or project) portfolio should remain compliant with the company's targets concerning the portfolio's overall strategic fit, value, and balance. For example, in company C, scorecards were used to evaluate new requests, and the evaluation criteria varied according to the extent of the requested change and included customer classification, net present value, technical risk, market growth, competitive advantage, personnel competence, and the request's long-term demand compared to the total production capacity.

The analysis should consider whether the request can be met by the current standard offering or previous customer-specific designs, or if a new design is needed. The development process should be selected according to the extent of the requested design change. Thus, each item on the technical structure should be given a classification based on estimations of the complexity of the modification of the part, and the classification data should be copied for the corresponding sales items. In company D, these data were linked to the sales item groups. Here, several viewpoints may need to be considered, for example, the required design and capability creation work, supply chain alterations, and product costs over lifecycle. Then, if the offer is accepted by the customer, the suitable development process, an ETO service sales item, can be chosen accordingly. The number of the processes, their contents, and decision-making criteria may vary depending on the company.

If the current standard offering does not meet the customer requirements, the customer-specific offerings can be checked to find if any of the previous customer-specific commercial sales items could meet the need. If any of the existing customer-specific sales items meet the need, a design reuse process can take place by applying the sales item to the new configuration without the need to develop any new designs (Fig. 2). Product management needs to keep a record of the demand of the customer-specific sales items to make decisions on whether some of them should be included in the standard offering.

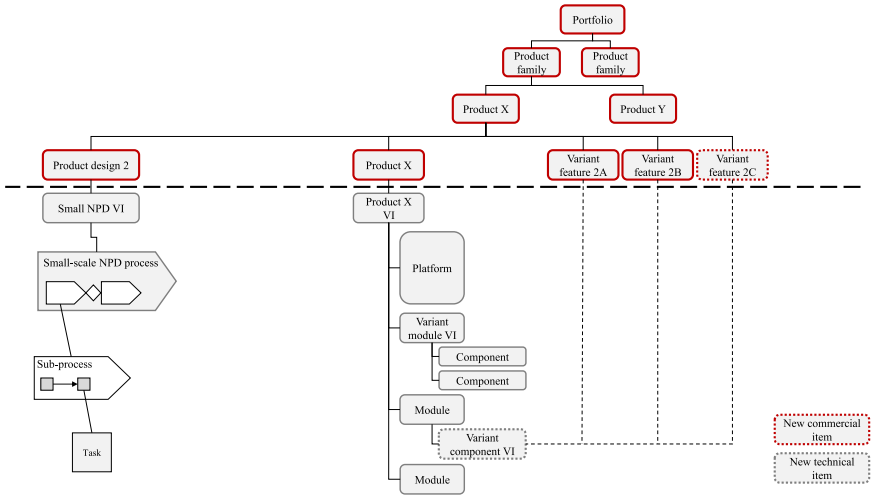

Fig. 3. Productization through the small-scale NPD process.

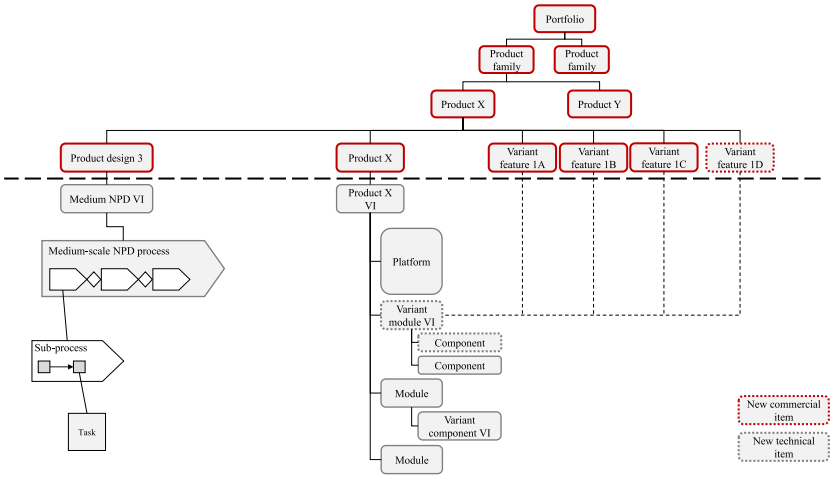

Fig. 4. Productization through the medium-scale NPD process.

If none of the previous customer-specific sales items can be applied to the new configuration to meet the customer's need, some development work is needed to modify an existing technical design and to create a new sales item. The sales item can be a variant for the existing features or an optional, add-on feature. If the customer need can be met by a small modification, e.g., changing a component, a small-scale NPD process can take place by adding the new component to the technical structure and creating a new technical version item and the corresponding commercial sales item (Fig. 3). An example of a modification of this level is changing the color of the product.

Customer needs that require more engineering than only component changes should be handled through the NPD process of medium scale (Fig. 4). As such, changes occur at the module level and probably require an engineering team consisting of members with diverse skills. Changes to the supply chain may be needed. As a result of the process, new technical modules are developed and new version items, as well as their corresponding sales items, are created.

When meeting the customer needs requires significant changes to the product or developing new platforms or technologies, a large-scale NPD process should be conducted (Fig. 5). In the commercial portfolio, this results in new products or product families. In the technical portfolio, these kinds of changes create a totally new product architecture and technical structure. A more systematic NPD process and a full development team are needed, and changes to the supply chain are expected.

When a new technical design is created as a result of a customer order, the new design should be given a respective sales item on the commercial portfolio. In the postdelivery analysis and decision-making, the actual costs of the new design should be calculated, and decisions on adding the new sales item to the standard offering or a customer-specific offering should be made. For example, in company D, communication of the decisions was strengthened by creating a new data attribute to classify whether a new version item was standard or project specific. Even if added to the customer-specific offering, adding the change to the commercial portfolio as a sales item will provide

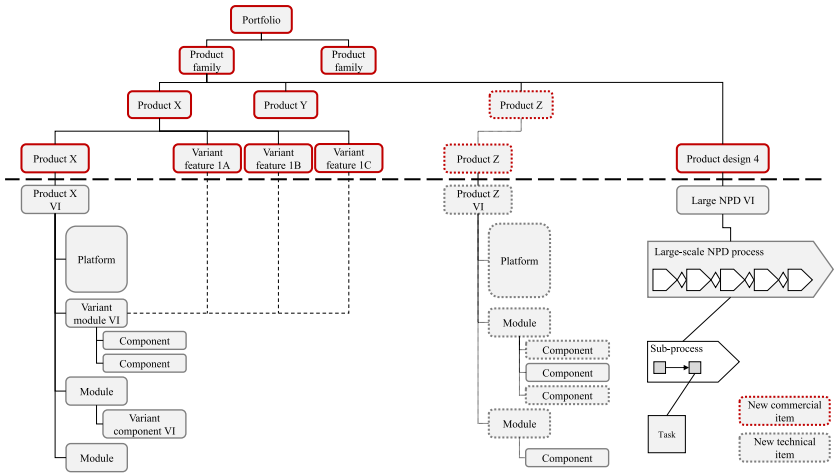

Fig. 5. Productization through the large-scale NPD process.

help in the future if some other customers are asking for similar features. For sales, it is easier to go through customer-specific commercial sales items than explore customer-specific technical structures. The standard offering should be analyzed regularly to ensure that the offering meets the company's strategic product portfolio management targets. The related decision-making may lead to adding new sales items, modifying the existing ones, or removing the sales items to avoid the explosion of the offering. In companies B, C, and D, a new data attribute, lifecycle status, was created to better know which items could be sold and delivered.

The constructed model should enable creating a common understanding of the commercial and technical items in the portfolio and creating a link between them. The interviewed experts had seen similar elements—divided product development processes and generic product structures—in their work but linking them to each other was seen novel approach and worth a try. The constructed model should be sufficient to make a clear separation between the customer-specific variants and the standard products based on which the negotiations and tendering can be easily started. As the standard parts of the offering can be identified, their lead times and costs can be estimated accurately. Considering the offering commercially and technically and including the services in the productized offering may support efficient product development, product profitability calculations, and lead time estimation, hence improving offer making. Modular product architecture supports the use of the model.

V. Discussion

This study aimed to improve the productization practices of ETO companies to enhance their negotiations and tendering. The current practices of four ETO companies were investigated to reveal the challenges related to productization and product structures. On the basis of the challenges and previous literature, a productization model was constructed.

It is indicated that ETO companies are struggling with various issues related to the lack of a comprehensive and consistent understanding of their products. The findings indicate that employee understanding of the offering can be improved through productization and the commercial and technical perspectives. This involves customer requirements, and specifications [27], and providing means for knowledge reuse [8]. The ETO business is challenged by unnecessary unique part numbers, bills-of-materials, and production routings [1]. The current product structure models for ETO companies (e.g., see [12]) offer support for design reuse to a certain extent and can benefit from productization in different types of design changes. The lack of appropriate productization yields challenges in negotiations and tendering in many ways. As the definition of the commercial side of the product portfolio is unclear (there are no definitions of the standard offering), it is difficult for sales to know what can or is allowed to be offered, and the customer cannot be effectively communicated about what they can order and how the offering would meet their needs. Productization enhances keeping track of product and process changes [16] and supports negotiations and tendering by improving the understanding of customizable elements [13]. The productization discussion [12], [17]–[20], [33], [35] can benefit of the ETO context examples of this study. The challenge of deficient understanding of the offering and the possibilities results in sales making promises that cannot be fulfilled. The situation can be alleviated through productization. ETO companies are advised to pay attention to how they define the commercial view of their offerings. Further, if the connection to the technical offering has been missing, the use of previous designs becomes challenging when the designers may have not known how certain features have been realized previously. This may result in unnecessary design work, an increase in design and production engineering costs, and extended lead times. The product structure thinking is linked to product development processes [22], [39] and supports the systematic and generic approach to customer requests, to enhance design reuse, sales, and offer making through the clarified offering. The notion that processes cannot perform unless the offering is under control is supported by understanding how productization provides means for this [54]. Sales must have a view over what

technical solutions are to be used to realize a specific feature, to enable giving the reasonable price and lead time estimates in negotiations and tendering. The sales must be provided with the knowledge to understand the extent of a design change. Utilizing a generic product structure may help with these issues, but such structures seem to be nonexistent. Also, product-related services, such as product design, seem not to be considered as structured processes. This means that setting the price margin in tendering to cover these costs might be arbitrary and hinder the total cost estimations for products and setting a reasonable price. Companies in the ETO business should consider productizing design work as service processes to better manage the costs. The offering can be complemented by productized services [52], [53].

ETO companies are also dealing with the challenge of proliferating the number of items in their IT systems [1], [4], [13]. Due to the lack of clear productization practices, each product with a new design may be added to the IT systems as a separate item, hence proliferating the base of individual designs and further hindering the product understanding. ETO companies should have clear processes and rules for adding new items to the standard offering, and the customer-specific one-time delivery designs should be kept separate from the standard offering to maintain the understanding over the offering to help the sales in negotiations and tendering.

This study presents a productization model, including commercial and technical product structures to be utilized in the ETO business to improve negotiations and tendering by creating a consistent understanding of the company's offering for all stakeholders. This provides systematics to enable linking the ETO order-related decision-making to product (or project) portfolio management targets and company strategy [41], [55], [56]. The previous literature [3], [7], [35] is provided support for addressing the challenges of ETO business. The model was found practical to implement, to improve negotiations and tendering in ETO companies whose extent of design changes varies from low–mid to mid–high. The product portfolio understanding is proposed to be supported by the utilization of a generic product structure. The commercial side is more relevant to sales and customers, whereas the technical side is more relevant to engineering and manufacturing [35]. Through productization, the sales can better know what can be offered and what the configurable or customizable features of the products are. Negotiations and tendering become more effective as the communication between the company and its customers improves. Traditionally, new customer orders have been considered individual projects in the ETO business. Improving the focus is proposed through the realization that the offering must be productized also when the work is in project form.

VI. Conclusion

Regarding the first RQ—how productization-related challenges hinder negotiations and tendering in ETO companies—the results indicate that deficient productization causes challenges in ETO companies and seems to hinder negotiations and tendering through the lack of a comprehensive and consistent understanding of products. Productization had significance with commercial and technical considerations, and the linkage of these perspectives, affecting how the offering was perceived internally, and by customers. The commercial side of the offering being unclear results in sales not fully understanding what can be offered. The negotiations tend to go over technical because of the fuzziness. This will impact the understanding by the customers as opposed to a situation with concrete deliverables. The customers may have difficulties grasping the possibilities and understanding the value. This drives the negotiations toward the customers explaining the technical needs. Sales were then incapable of linking the needs to the existing offering, which challenge communication, and hinder negotiations and tendering. The opportunity to design reuse was lost. The nature of ETO business of engineering products to each customer according to customer wishes may further emphasize the effects of unclear offering when the base offering was not under control. The company processes were affected by this. The unclarity with the commercial offering and the resulting challenges were emphasized by the deficient linkage between the commercial and the technical considerations. This adds to design and engineering work, and costs, and negatively affects the lead times. The deficient linkage further hinders understanding costs and affects pricing for customers. The deficient productization results in sales and other company functions not having a common understanding of the offering and the related product structures. This challenges internal cooperation during negotiations and tendering. The situation was further complicated by offering related challenges with the company's IT systems.

Regarding the second RQ—how can productization be utilized through the commercial and technical product structures to improve negotiations and tendering in the ETO business—the results indicate that productization can improve the negotiations and tendering in ETO business through addressing the commercial and technical product structures, and by providing means for a consistent understanding of the offering. Sales can better grasp the extent of design changes through maintained product structure. Also, the linkage to technical solutions to be used becomes clearer. This improves the price and lead time estimates. The possibilities for design reuse will improve through consistency in understanding. Communication toward customers and peers was supported by productization creating a common language. Dealing with product versions and variants will improve through the resulting clearer distinction between standard and customer specific. The overall product and the configurable and customizable features will be better under control, allowing processes to perform. The use of IT systems becomes more effective as new items were not created unnecessarily but only certain features were modified. Further IT-related challenges were also avoided as clearer rules for modifications can be set. This will drive design reuse in the ETO context, improve negotiations and tendering.

A. Theoretical Contribution

This study provides a unique contribution to the ETO business-related discussion by highlighting the significance of

productization and considering the commercial offering and its linkage to the technical realization alongside the technical product. It is highlighted how ETO negotiations and tendering can be improved by making the offering understandable and communicable to all stakeholders through adequate productization. Contribution was provided by indicating how the offering can be brought under better control, to allow processes to perform. Productization allows improved consideration of fixed elements and those that can be designed customer specifically, supporting the nature of ETO business, while avoiding the challenges of uncontrolled proliferation of designs. The importance of supporting the adequate understanding by sales, gaining a common language, and design reuse were emphasized. This will support ensuring product profitability and making lead time estimations and enhance the negotiations and tendering process.

B. Managerial Implications

The company managers involved in ETO business may benefit from understanding the model introduced in this study to productize the companies' abstract product offerings. The model may help in gaining a uniform understanding of the offering within a company. Defining the standard offering commercially by separating the standard variant features and the customer-specific features should help in clarifying what can be offered to the customers. Linking the commercial features, sales items, to their respective technical version items should better enable cost calculations and more accurate lead time estimations. Product-related services, such as design and installation, should be included in the product structure to support the calculations. Further, new product design and management can be improved by linking the product structure to the different scales of product development processes for different types of customer requests. The decision-making in the processes can be linked to the company's product portfolio management targets and strategy.

C. Limitations and Future Research

The limitations of this study include the number of studied companies. The constructed model was created for certain types of ETO companies. The model may not apply to ETO companies whose business was based on creating new products from scratch. These kinds of companies could have better use of a model that focuses more on the service type of an approach. For companies whose design changes were low and were done at the point-of-delivery, the presented model may not provide much additional value. Constructing a model in the context of ETO companies with fully customized products could act as an area of interest for future research. Also, the modularity theory had linkages to productization, specifically the technical considerations, making it an interesting branch for future studies.

APPENDIX A
THE INTERVIEW QUESTIONNAIRE

1) General questions about the interviewees, their roles, experience, and the company and its customers.
2) Productization and commercial and technical product portfolios.
   a) How would you define a product?
   b) Do the company's products consist of physical products, services, software, combinations, or something else? Please describe.
   c) How many products and sales items are there in your company's product portfolio?
   d) How are the products grouped/divided into product families?
   e) Are there comprehensive descriptions of what products can be sold/what products the customers can buy?
   f) Are there comprehensive descriptions of how the products are manufactured?
   g) Is there a clear connection between the commercial (sellable) items and their technical counterparts?
   h) Is customer-specific product design (ETO work) considered and described as a process?
   i) Are the products based on common platforms or modules? Please describe.
   j) What are the challenges related to productization and understanding the commercial and the technical product portfolios?
   k) How would you solve the challenges?
3) Order-delivery process.
   a) What is the order-delivery process in your company like? Please describe.
   b) What are the different roles in this process?
   c) How does the communication between the sales, design, and manufacturing work?
   d) Do the following happen often? Why?
      i) The sales sells something that cannot be manufactured.
      ii) The selling price of a product is found out to be too low compared to its actual costs.
      iii) The delivered product does not correspond to the product sold to the customer.
   e) What are the challenges related to the order-delivery process?
   f) How would you solve the challenges?
4) PDM.
   a) How often are you dealing with product data in your work?
   b) How are product data related to your work?
   c) What IT systems/tools/applications does your company use?
      i) Design tools?
      ii) PDM/PLM tools?
      iii) Sales and marketing tools?
      iv) Delivery/supply chain tools?
      v) Service and care tools?
      vi) Others?
   d) What kind of data/information do they create, use, or store?
      i) Product master data?
      ii) Business process-related product data?
      iii) Other master data?

iv) Other data?
e) Do the product data include data about the product's lifecycle? What are the lifecycle stages?
f) How are the systems/tools/applications integrated?
g) Which of them do you use in your work? How?
h) Do you use a lot of time on searching for data in the systems?
i) What are the challenges related to PDM?
j) How would you solve the challenges?

5) Product structure.
a) Does your company have a consistent product structure logic? If yes, what is it like? If no, what kinds of structures are there?
b) Does the product structure logic acknowledge the commercial and technical sides of the offering?
c) Does the product structure logic support the different business processes of the company?
i) Product process?
ii) Sales and marketing process?
iii) Delivery/supply chain process?
iv) Service and care process?
d) In which IT system is the product structure managed?
e) What are the challenges related to the product structures?
f) How would you solve the challenges?

6) Management of product variants and versions.
a) How many variants are there for each product?
b) Do you think that the variability of the company's product offering is appropriate, too high, or too low? Please explain.
c) What are the configurable elements of the products?
d) What is the configuration process like? Does it fit the company's purposes?
e) What are the customizable elements of the products?
f) What is the customization process like? Does it fit the company's purposes?
g) Are there rules or criteria for customizing the products? Please describe.
i) Who evaluates and makes the decision on whether the order can be accepted?
h) What are the standard elements that cannot be customized?
i) Are there exceptions to this? Please describe.
ii) Who has the authority to make the decisions?
i) Is the distinction between the configurable, customizable, and standard elements clear?
j) How are product variants managed? Please describe the creation, upkeeping, and removal of standard variants.
i) Customer-specific variants.
k) What are the related roles?
l) How are product costs tracked?
m) How do you get the needed information for cost tracking?
n) How do you know how much a design change will affect the product's
i) design cost?
ii) delivery/supply chain cost?
iii) service and care cost?
o) How are new product versions (revisions) managed? Please describe.
p) Does product variation cause challenges in your company? Please describe.
q) How would you solve the challenges?

7) NPD and project management.
a) Does your company have a process for developing totally new products or product families? Please describe.
b) What are the different roles in this process?
c) How many totally new products or product families do you usually have in development?
d) How do such projects differ from customer-specific development projects?
e) What are the drivers or triggers of initiating such a project?
f) Does the current NPD and project management cause challenges? How?
g) How would you solve the challenges?

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