Chapter 2
Reconfiguring Variety, Profitability, and Postponement for Product Customization with Global Supply Chains

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2.1 Introduction

With the emerging area of mass customization, researchers and practitioners alike have acknowledged a growing trend toward higher product variety and customization. Customizing a product can be described as the process of configuring a product variant by selecting predesigned components within a selected scope of offered variety [1]. Companies employ customization as a means to differentiate from their competitors by providing unique customer value [2]. Although many positive commercial advantages can be named from offering extensive customization [3], recently a stronger focus has been laid on the downside of the added supply chain complexity [4]. Higher product mixes created through diverse manufacturing strategies have been identified as major complexity drivers throughout value chains [5], often leading to reduced operational performances, such as longer lead times, poorer quality, and increased costs [6, 7]. Hence, integrating approaches to complexity management into the framework of supply chain management (SCM) has become compulsory [8].

A major concern in SCM is to systematically and strategically coordinate material flows across companies with the objective of reducing cost and achieving competitive advantages [9]. To account for the immanent complexity from customization, the scope of SCM needs to be aligned with aspects of variant management and postponement, i.e., the degree to which customization is provided throughout

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the supply chain [10, 11]. This chapter adds to the existing knowledge of how supply chains dealing with varying degree of customization can handle the arising complexity. Based on a literature study on designing and managing supply chain networks for customization (Sect. 2.2), Sect. 2.3 introduces a suggested approach for the reconfiguration of the network design. Next, a case study is presented in Sect. 2.4, where empirical evidence is provided on how postponement and substation may positively reduce complexity and simultaneously increase companies' overall profitability and operational performance.

2.2 Literature Review

2.2.1 Product Customization with Global Supply Chain Networks

To compete on international markets, manufacturing companies are organizing their business processes around a global supply chain network [12]. Figure 2.1 displays a conceptual model of a hypothetical supply chain network design. From a high-level perspective, supply chains may typically include activities related to engineering and purchasing, manufacturing, assembly, distribution, and sales. To serve the needs of local markets, traditionally these activities have in their simplest form been established within the country of origin. With globalization firms have over time been moving toward international markets, for which some of the supply chain requires to be outsourced or physically displayed [13]. As indicated in Fig. 2.1, depending on the sales strategy, to secure lead times and product delivery, sales may, for example, be displaced to target markets, thereby establishing local sales

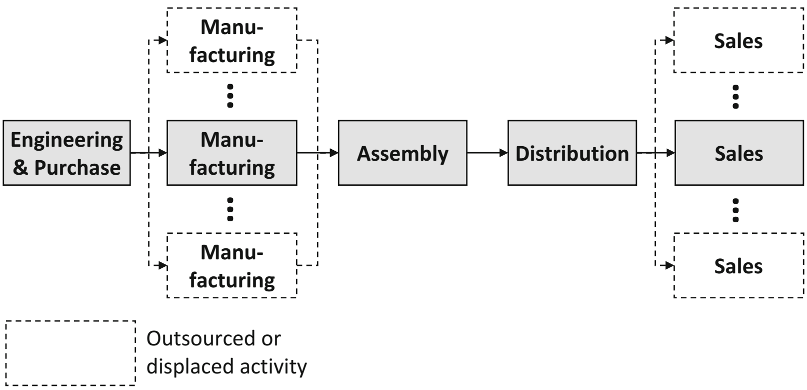

Fig. 2.1 Conceptual global supply chain network with outsourced or displayed manufacturing and sales

channels. To lower product costs or to focus on key competences, manufacturing on the other hand may be outsourced or displaced to low-cost countries, keeping the final assembly of components in the country of origin [14]. An example of this approach can be seen in the apparel industry, where products are designed in the country of origin, often manufactured in others, and sold locally within target markets [15]. In more general terms, the relative cost advantage of low-cost countries and the small value added to the final products is often named to be the main motivation for emphasizing this particular part of the supply chain, like manufacturing [16]. To this end, several studies have investigated the possible gains and motivation from reconfiguring supply chain networks. While major part of the research suggests an overall positive effect on the firm's performance, few studies also point out the potential risks with this strategy [17].

In addition to the network design of a particular supply chain, offering product customization requires consideration about the product design and production planning and control system. The degree to which customization is provided can vary across the entire product portfolio of a company and is often described through the relative involvement of customers with the companies' supply chain, i.e., to the customer order decoupling point (CODP) [18]. As displayed in Fig. 2.2, the more supply chain activities are directly related to a particular customer order, the higher is the degree of the offered variety and the early in the supply chain the CODP is placed. Literature names a few distinct product planning and control systems allowing for customization, depending on the relative placement of the CODP [19]. In an Engineer-to-Order (ETO) situation, components have to be engineered based on a specific request from customers, forcing all subsequent activities to be directly engaged in fulfilling the order. Due to the early customer involvement, typically ETO products obtain a large amount of variety, but their production volumes are low [20]. In a Make-to-Order (MTO) scenario, predesigned and available components are used for manufacturing and subsequent assembly of the product variants. In case both engineering and manufacturing activities are performed based on forecast, subassemblies from stock are used in the assembly process to Assemble-to-Order (ATO) the requested product variant. To account for a high

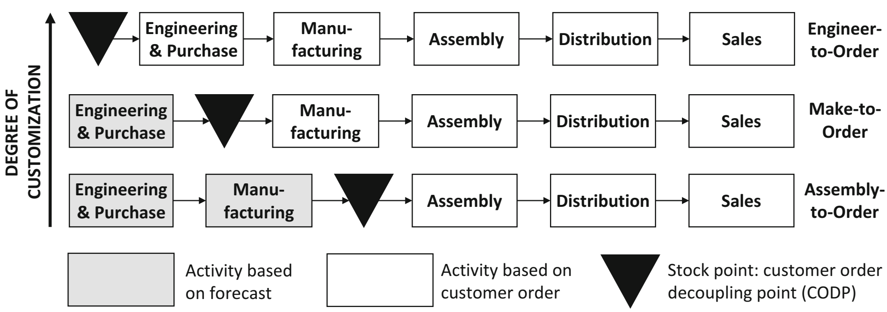

Fig. 2.2 Degree of customization and placement of the CODP

amount of final variety, a modular product design has been reported to facilitate the separation between manufacturing of components and (final) assembly [21]. With the so-called modular product architecture, components or modules can be produced or outsourced based on forecast and recombined according to the requirements of the customer [22]. This would allow the company to postpone the CODP closer toward the customer, i.e., to an MTO or ATO situation. The so-called Type III postponement strategy aims at capitalizing on standardization and modularity, thereby achieving economies of scale [23].

2.2.2 Supply Chain Performance and Reconfiguration

Despite the rather simplistic view on the production process, dividing the different production planning and control systems according to the placement of the CODP helps to define clear strategies for a particular supply chain network design. Decisions about a suitable configuration of the network may be related to key operational performance measures of a company, such as to cost and time [24]. From customers' perspective, higher degree of customization allows for more engagement in the supply chain and hence to more unique product designs. However, since more activities have to be performed after a specific order has been placed, there is a tradeoff between the uniqueness of the product design and the related delivery time and cost. In general, the higher the number of activities performed for a customer, the bigger the sum of the individual lead times of each process [2]. Moreover, unique designs with higher engineering engagement have often proved to be more costly and less quality assured [25]. Since a higher percentage of the supply chain is performed based on a distinctive customer requirement, processes are less standardized and may involve ad hoc and unproven tasks which require stronger coordination effort [20]. On the other hand, with an MTO and ATO strategy, the increased standardization of components and processes combined with reduced delivery times has shown to be particularly useful for products with moderate or limited variety and high volumes [18]. Therefore, setting the right strategy for the production planning and control system can have a wide-ranging impact on the profitability of the provided portfolio.

Traditionally, decisions about the placement of the CODP are made based on inventory management theories and may include aspects of inventory cost, lead time requirements toward the market, sales volume and order frequency, and scope of offered variety [26, 27]. Accordingly, items with low volumes and high variety should be organized around an early placement of the CODP and vice versa. Recent literature however emphasizes that more and diverse customization significantly increases supply chain complexity, making cost allocation and prices estimations less accurate [8]. Planning with higher product variety often leads to overestimated profits, where the complexity-induced cost of the supply chain is not taken appropriately into account by traditional accounting methods [28]. Schuh et al. (2008) discuss complexity from two forces [29]. External complexity occurs due to desired customer requirements. This defines the number of the offered product variety. Internal complexity describes the processes, parts, and product designs across supply chain needed to provide the demanded product variety. Reducing the internal complexity as much as possible by obtaining the necessary external complexity is seen as a guiding principle for managing the complexity across supply chains [1].

A common way to identify unnecessary external complexity is to investigate the realized contribution margins (CMs) for each variant according to the Pareto principle [30]. As studies have shown, in complex supply chains, a large amount of the sold variants do not contribute if at all to the turnover of firms. Instead, a major part of the turnover is generated from a small amount of the variety [31]. In order to classify which variants to keep and which to reduce or replace, a categorization into A, B, and C products is typically performed [32]. Once unprofitable variants are identified, various initiatives can be enforced to reduce the related complexity. Depending on the product design and the supply chain network, such initiatives may include the increase of modularity [33], postponement [11], or product standardization through increasing component commonality [34].

Yet, due to the rather sensitive operational data, empirical-based research considering both analysis on margins and the related initiatives is rare. Hence, the main focus of this research is to find empirical evidence on how to identify the most profitable product variety for product customization regarding production strategy and supply chain setup. In particular this research attempts to answer the following research question:

RQ1: How can the operational and financial performance of a supply chain network for customized products be improved?

This research question is answered based on the three subquestions:

RQ1.1: How can customized products be categorized relative to their degree of customization?

RQ1.2: How can the potential for a postponement of the CODP and a standardization strategy be identified?

RQ1.3: How can postponement and standardization effects on costs and contributions margins be quantified?

2.3 Suggested Approach

As stated in the previous sections, complexity creates uneven cost distribution across the different product variants. Based on the literature, moving the CODP toward the front-end is an effective approach to complexity cost reduction. However, in cases where the manufacturer produces not only ATO products but also MTO and ETO, the setup varies a lot among the different production strategies. On top of that, the profitability assessment may be calculated through several approaches. Recent literature suggests that in order to have a clear picture of the "high runners" and the "long tail," both CM and sales volume have to be taken into consideration in the profitability analysis.

In alignment with related contributions, this research suggests an approach for profitability analysis and complexity reduction, which can be applied to manufacturing companies with different production strategies. In order to analyze the profitability, an ABC product categorization is performed. Each product is grouped into A, B, or C based on its CM and net revenue (NR), which enables the consideration of the sales volume for each variant. To reduce the supply chain complexity, two coordinated methods are considered. The first one relates to postponement of the CODP and the resulting product standardization. Besides, complexity reduction theory suggests the development of modular products that consist of standard subassemblies. In that way when an order is placed by the customer, the final configuration of the product can takes place with an MTO or ATO approach. This strategy reduces lead time, complexity cost, and production cost. The second method discusses the provided variety of the product portfolio in terms of cannibalization and profitability. Related literature highlights that the increasing variety offered to the customers does not necessarily indicate that a wider range of application is covered. In order to ensure that variants with different production cost and sales volumes are not offered with similar properties and applications, product merging through substitution is suggested. This is done by analyzing the bill of materials (BOMs) and the CMs of these variants.

2.4 Case Study

2.4.1 Data Collection

The suggested methodology is applied on a case study of a Danish manufacturer of pumps. The company produces standardized as well as more specialized products with an ATO, MTO, or ETO strategy. The main market requirements for pumps are reliability, functionality, design, price, delivery performance, and solution flexibility. The product portfolio of the company includes pumps for chemical, environmental, heavy, and petrochemical duty and for general purpose. The data collection is performed through the company's internal database and includes BOMs, total cost, NR, sales volume, production strategy, and country of production and distribution, on finished good level. The sample size refers to sales within a 2-year period (2012, 2013). Semistructured interviews with project managers are performed, in order to verify the accuracy of the data acquisition.

As suggested in literature, since part of the supply chain is based on forecast, the ATO products have relatively shorter lead times and better delivery performances. MTO products are produced based on an order received from the distribution center (DC). They consist of standard parts, which additionally require special treatment, and are produced in low runs. Before their components can be produced, BOM and prices have to be verified, which results in longer lead times compared to the ATO variants. Special customer requirements are treated as ETO products and hence obtain longer lead times and higher cost in comparison to the ATO and MTO products. A significant difference between an MTO and an ETO product is that for the latter, a dedicated production setup is required, which involves alternative processes and tooling. Moreover, the R&D department is also involved in the enquiry and quotation process, to verify the feasibility of the customer's requirements and to ensure the supply chain capabilities.

The company acquires two production sites, one in Denmark and one in China, and three DCs, one in each of the following countries: Denmark, China, and the USA. The DCs in China and Denmark deliver products produced to the respective site; the North America market is supplied by either China or Denmark. However, the products distributed in Denmark are produced in two ways; either they are entirely produced in Denmark (local) or they are produced as standard semifinished units (SFU) in China, and then the final configuration and testing is performed in Denmark (Figs. 2.3 and 2.4).

The sample size focuses on one representative product family consisting of 299 variants, the heavy duty (HD) pumps consisting of a modular product architecture.

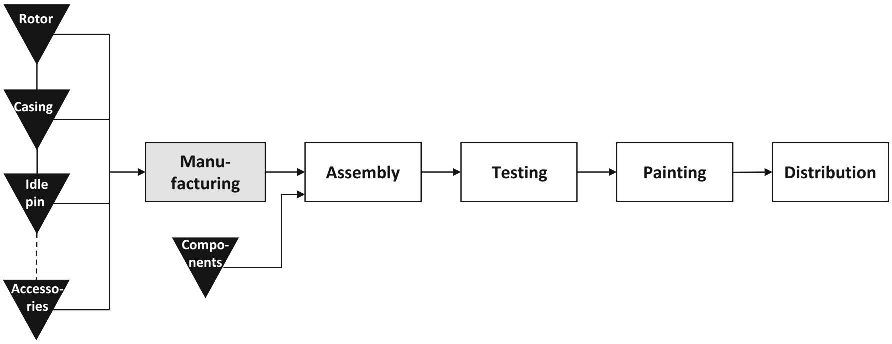

Fig. 2.3 Local production in Denmark

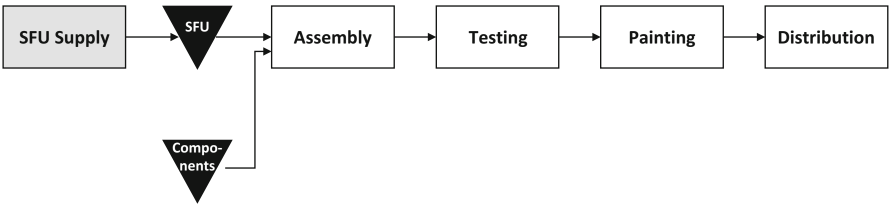

Fig. 2.4 SFU production in China and final configuration in Denmark

The particular product family is selected due to its significant share of the total sales, which accounts for 60.61 % of the total revenue. Moreover, HD pumps are offered based on all three production strategies with a distribution of 32, 33, and 34 % between ATO, MTO, and ETO accordingly. To limit the scope of analysis, the sample size refers to products being sold from the DC in Denmark.

2.4.2 Analysis and Results

Currently, the company categorizes the products as A, B, and C based on their inventory turnover and their picking frequency. The results from this internal ABC analysis are presented in the following table (Table 2.1).

The ABC categorization is based on internal experience. Products are categorized as A if they have inventory turnover higher than or equal to three and picking frequency higher than or equal to 20. B products are indicated by inventory turnover equal to two and picking frequency between three and 20. Finally, C products have inventory turnover less or equal to one and picking frequency less or equal to three. All the data refers to a 12-month period.

Both parameters, inventory turnover and picking frequency, are related to the sales volume of the products. However, with this internal categorization approach, none of the measures accounts for the CM of the products. Yet according to the literature, in order to draw conclusions regarding the profitability of a product, the NR and production cost have to be taken into consideration. This results in questioning the accuracy of the internal ABC product categorization.

By implementing the suggested methodology, an ABC analysis is performed, which categorizes the products based on the NR and CM instead. The CM is calculated as the difference of the NR from the direct production cost, where direct production cost includes the cost of material and labor. The following table presents the results of the ABC analysis (Table 2.2).

When comparing the results from the two ABC analyses, it can be concluded that in the company's perspective, many C products are kept in stock (81.6 %), which leads to increasing inventory costs and consequently complexity costs. From the suggested ABC analysis, the ratio of C products is relatively lower (77.3 %). Yet the distribution of products varies between the two analyses, indicating that further research is required to identify the cause of this divergence.

Table 2.1 Internal ABC analysis

Inventory turnover	Picking frequency			
	Category	A (>20)	B (4–20)	C (0–3)
	A (≥3)	18	2	0
	B (2)	11	24	5
	C (0–1)	3	46	190

Table 2.2 ABC product categorization based on CM and NR

NR	CM			
	Category	A	B	C
	A	38	23	11
	B	0	7	88
	C	0	0	132

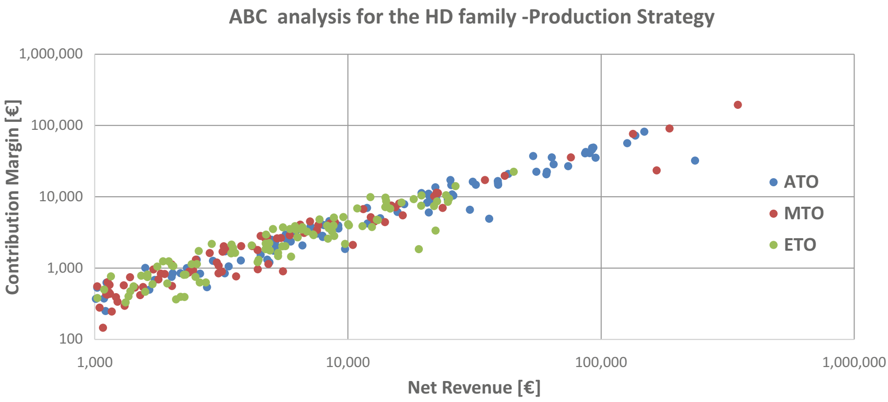

Fig. 2.5 ABC product categorization by production strategy

To gain better understanding of how postponement may be applied, the results are displayed in relation to the three production strategies (ATO, MTO, ETO). In other words, the products are categorized into A, B, or C, based on their NR and CM, revealing a significant difference between how the type of products are included under each production strategy.

As displayed in Fig. 2.5 above, 60 % of the ATO products are categorized as C products. 29 % of the ATO variants are categorized as A and the remaining 11 % as B products. However, this result highly contradicts to the internal categorization of a product ATO. ATO products are standardized, are produced in large batches, and are high runners. That implies that ATO products have lower production cost and higher revenue, which would result in higher CM and, consequently, in an A product. Less contradictory, only 8 % of the MTO belong to A and 87 % to C products. Finally, as expected only 2 % of the ETO products are A and 88 % C.

In detail, the following table presents the total cost, NR, CM, number of variants, and sales volume per production strategy.

The results from Fig. 2.6 indicate that the ATO products are more profitable, contribute far more to the company's profitability, and are sold in higher volume. However, this again does not conform with the result from the internal ABC analysis (see Table 2.1), which shows that 60 % of the ATO products are C. Based on the

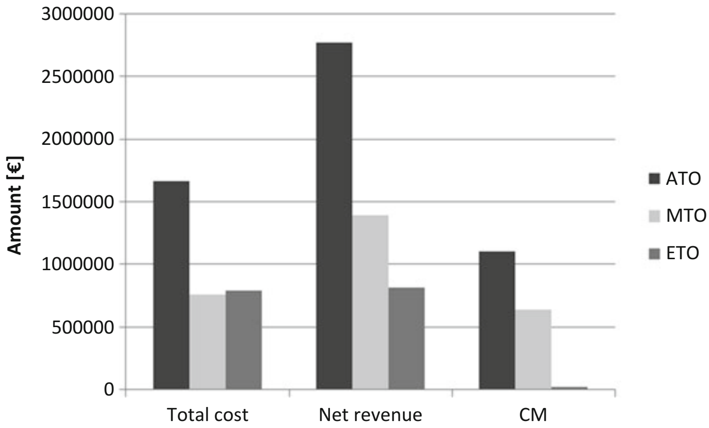

Fig. 2.6 Comparison of the financial data from the three production strategies

above, a re-categorization of the products under the three production strategies is recommended.

By following the suggested research method, two approaches are implemented. The first one aims at increasing the standardization of the ATO products. The company, as discussed above, uses SFU manufactured in China as preassemblies for the ATO products. The products including these SFU have significantly lower production cost. However, out of the 97 ATO variants, only in 8 % of the cases outsourcing through SFUs is used. The following Table 2.3 gathers the relevant financial data for the products produced in China and in Denmark.

To identify the potential for outsourcing, products with similar properties and sizes produced in Denmark and China are investigated. By increasing the number of SFUs used in the final assemblies, the overall number of variants produced is significantly reduced, thereby decreasing the complexity of the supply chain. The following Table 2.4 illustrates the results of those calculations.

For further product standardization, a re-categorization of the products among the three production strategies (ATO, MTO, ETO) is examined. Products with same sizes are analyzed based on their production strategy with the intention to move as many products as possible to the ATO category. Decisions are made after comparing the BOM and the functional properties of the products. This analysis results in increasing the standardization of 36 products, or 12 % of the portfolio. In detail, 18 MTO and 18 ETO products are moved to ATO category. The financial impact is illustrated in the following figure (Fig. 2.7).

Summarizing the results from the two standardization methods discussed above, it can be seen that the total cost of the HD family is decreased by 4.3 %. The impact of the implementation on the NR is not significant, due to the lower sales price the standardized products have compared to the customized ones. Yet, the increase in

Table 2.3 ATO products

Production country		Cost (€)	NR (€)	CM (€)	# of variants	Sales volume
CH	Sum	8.826	14.269	5.444	8	273
	Aver	1.103	1.784	680	–	–
DK	Sum	109.347	194.853	85.505	89	1264
	Aver	1.229	2.189	961	–	–

Table 2.4 Financial data after implementing the SFU standardization

	Before (€)	After (€)	Difference (€)
CM	3.370.800	3.388.987	18.187
Revenue	6.436.071	6.076.030	–360.041
Cost	3.065.271	2.687.043	–378.228

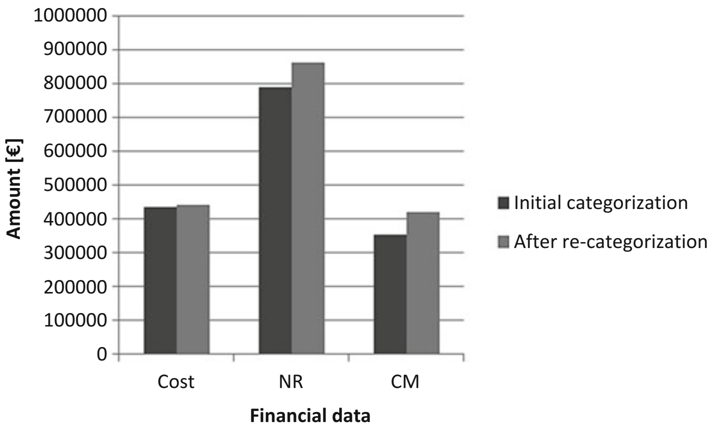

Fig. 2.7 Comparison of financial analysis of the production strategy categorization

the CM by 18 % (from 354.299€ to 419.314€) indicates that the profitability of the new product portfolio has been positively affected (Table 2.5).

Next, the potential for substitution is being investigated. The analysis is made in ten groups of products that have the same size. In particular 98 product variants are merged into 44, where 20 out of them are merged into 13 products that have SFUs produced in China as preassemblies. By merging the products, 54 variants can be eliminated, which additionally reinforces the standardization of the product family.

In order to estimate the total effect on the company's profitability after implementing the suggested method of both product standardization and variant

Table 2.5 Total impact on the HD family

	Before (€)	After (€)	Total impact (%)
Total revenue	4.977.942	4.996.389	0.4
Total cost	3.212.839	3.074.773	–4.30
Total CM	1.765.103	1.921.616	8.9

Table 2.6 Sensitivity analysis with four scenarios

	A (%)	B (%)	C (%)	D (%)
Cost	–20	–20	–20	–30
Sales price	0	–5	–5	–10
Sales volume	5	10	0	20

Table 2.7 Impact of the four scenarios

	1 (%)	2 (%)	3 (%)	4 (%)
Cost	–3	–2	–4.1	–0.8
NR	1.8	1.7	–1.2	1.5
CM	10.5	8.3	9.9	5.1

substitution, a sensitivity analysis is performed. The following table describes the four combinations that are used in order to gain a better understanding of the impact of the approach on the CM of the product family (Table 2.6).

For each of the above scenarios the cost, NR and CM are calculated. The results are as follows (Table 2.7):

The negative percentages indicate that there is a reduction after the implementation of the suggested approaches. The results demonstrate that the CM is increased in every case. It is worth mentioning that even in scenario 4, where there is no increase in the sales volume, the CM is increased considerably. As a result, the outcome of the sensitivity analysis indicates that the application of the suggested methods for product standardization and variant elimination has an impact on reduction of complexity costs and increase profitability.

2.5 Conclusion

This research examined the effect of postponement and product substitution on profitability and complexity reduction in the manufacturing industry. The suggested methodology was developed based on recent research studies and is further supported by empirical evidence. A particular pump manufacturer considered being highly representative for this research was used as a case study, due to its diverse production strategy with different degrees of customization and a global supply chain network. The case study investigated variants profitability and identified the realized degree of customization of a selected product range.

The results indicated that there is a significant improvement of the product's profitability once the standardization and substitution method is applied. By managing the existing variety of the product portfolio, eliminating the variants that add no value and/or no additional properties, and postponing the CODP, the operation performance in terms of profitability and lead time was improved. An 18 % increase in the CM of the ATO products was achieved by standardizing 12 % of the variants. Furthermore, additional effects were estimated from a subsequent variant substitution.

Despite being one of the rare empirical-based studies within this research field, since the results are supported by a single case study, the main limitation to this research is the generalizability. This provides opportunity for further research which would help to investigate the impact of the suggested approach on the different cost elements and complexity costs across a number of cases. Likewise, the distribution of complexity costs over the product range and the effect of the portfolio standardization and substitution are to be further examined. Here, additional case studies may to allow the generalization of the suggested method and further enhance the external validity of the results.

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