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Customer Focused Complexity Management

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PhD Thesis

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Preface

This thesis is based on an Industrial PhD project conducted by Tobias Kondrup Andersen in collaboration with the Technical University of Denmark (DTU), Innovation Fund Denmark and an international manufacturer in the plastics industry. The project spanned three and a half years, from 1 August 2019 to 31 January 2023, with this thesis serving to conclude the project.

This article-based PhD thesis incorporates content from four studies conducted to answer two research questions (RQs). The principal aim of this work was to develop greater insight into the ways in which manufacturing companies can manage complexity while minimising the loss of future business from existing customers. A summary of the articles in relation to the research questions is presented herein; the full-text versions are appended at the end of this thesis.

RQ1: How can manufacturing companies manage and reduce product variety while protecting the future business of existing customers?

A. A product variety reduction procedure that considers linked revenue

B. The role of linked revenue in product variety reduction: A procedure and two case studies

RQ2: How can manufacturing companies manage and reduce product-related service variety while protecting the future business of existing customers?

C. An approach for the development and implementation of configurators for product-related services

D. On-time delivery performance: Motivations for including customer requested date as comparison date

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Summary

Modern manufacturing companies operate in an increasingly complex world of customers demanding high-quality customised solutions, delivered quickly and at a low price. This has resulted in high levels of internal complexity leading to deteriorating operational performance. Therefore, the effective management of complexity has become a key competitive factor. However, the elimination of complexity may impact the ability of companies to satisfy the needs of their customers. The purpose of this PhD is to explore ways for effective management of complexity in manufacturing companies that also minimise the resulting negative impacts on the future business of existing customers.

This thesis presents a set of four studies exploring various elements of this challenge. First, a procedure for identifying unprofitable product variety for termination while minimising the resulting loss of business from existing customers is presented and tested. Next, an approach for the development and implementation of configurators that address the distinct obstacles related to the management of product-related services is proposed and tested. Finally, a systematic literature review is conducted to synthesise how on-time delivery (OTD) performance is defined and used in literature. Based on the identified gaps, the ways to improve the accuracy delivery performance measurement systems are explored.

The results of testing the proposed procedure for product variety reduction illustrate the importance and relevance of considering the resulting negative impacts of product variety reduction on the abilities of companies to satisfy the future needs of existing customers. The approach for the development and implementation of configurators for product-related services highlight the challenges and benefits related to better management of these services. The systematic literature review reveals significant gaps in the existing literature on OTD performance. By addressing these gaps, the study finds that the enhancement of delivery performance measurement systems can lead to valuable insights for improvements to the management of product delivery services.

Resumé (Danish)

Moderne produktionsvirksomheder opererer i en stadig mere kompleks verden af kunder, der efterspørger kundetilpassede løsninger af høj kvalitet, leveret hurtigt og til en lav pris. Dette har resulteret i høje niveauer af intern kompleksitet, hvilket har ført til forringet operationel ydeevne. Derfor er effektiv styring af kompleksitet blevet en vigtig konkurrencefaktor. Eliminering af kompleksitet kan dog påvirke virksomheders evne til at tilfredsstille deres kunders behov. Formålet med denne ph.d. er at udforske måder til effektiv styring af kompleksitet i produktionsvirksomheder, der minimerer den resulterende negative påvirkning af eksisterende kunders fremtidige forretning.

Denne afhandling præsenterer et sæt af fire undersøgelser, der udforsker forskellige elementer af udfordring. Først præsenteres og testes en procedure til at identificere urentabel produktvarians til eliminering, samtidig med at det resulterende tab af forretning fra eksisterende kunder minimeres. Dernæst foreslås og testes en tilgang til udvikling og implementering af konfiguratorer, der adresserer de særskilte forhindringer relateret til styring af produktrelaterede tjenester. Endelig udføres et systematisk litteraturstudie for at syntetisere, hvordan leveringssikkerhed defineres og bruges i litteraturen. Baseret på de identificerede huller udforsker afhandlingen måder at forbedre målingssystemerne for nøjagtig leveringssikkerhed.

Resultaterne af afprøvningen af den foreslåede procedure for reduktion af produktvarians illustrerer vigtigheden og relevansen af at overveje de resulterende negative virkninger af den reducerede produktvarians på virksomhedernes evne til at tilfredsstille eksisterende kunders fremtidige behov. Tilgangen til udvikling og implementering af konfiguratorer til produktrelaterede tjenester fremhæver udfordringerne og fordelene forbundet med bedre styring af disse tjenester. Det systematiske litteraturstudie afslører betydelige huller i den eksisterende litteratur om leveringssikkerhed. Ved at adressere disse huller finder undersøgelsen, at forbedringen af systemer til måling af leveringssikkerhed kan føre til værdifuld indsigt om forbedringer af styringen af produktleveringstjenester.

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List of acronyms

CCF	Complexity cost factor
CM	Contribution margin
CM2	Complexity adjusted contribution margin
CMR	Contribution margin ratio
CM2R	Complexity adjusted contribution martin ratio
CP-OTD	Customer-perceived on-time delivery rate
ERP	Enterprise resource planning
ETO	Engineer-to-order
JIT	Just-in-Time
PVM	Product variant master
RQ	Research question
SC-OTD	Supplier-confirmed on-time delivery rate
TO	Turnover

1 Introduction

Industrial companies have been operating in an increasingly complex world, which has resulted in high levels of internal complexity. As excessive levels of complexity lead to the deterioration of operational performance, the effective management of complexity has become a key competitive factor for these companies (Ramdas, 2003). However, the elimination of that complexity may impact companies' ability to satisfy their customers' needs. Consequently, method needs to be identified to allow businesses to manage their complexity while considering the impact of doing so on future business with existing customers.

1.1 The challenge of managing complexity in manufacturing companies

Complexity is on the rise in manufacturing companies due to factors such as globalisation (Lee, 1996; Ulrich, 2006) technological changes (Lee, 1996; Singh, 1997), mass customisation (Pine et al., 1993) and the tendency of companies with underutilised assets to extend their product lines (Götzfried, 2013; Quelch & Kenny, 1995). These factors can lead industrial companies to broaden their product portfolios by introducing new brands, functionalities and packaging types or by customising products to meet the needs of individual customers (Brun & Pero, 2012). Furthermore, they can motivate companies to enter new markets and expand their distribution channels, resulting in additional product variety as products are adapted to meet the requirements of these new markets (Bilgen & Günther, 2010).

The results of a survey of 62 managers of global companies showed that 25–30% of global companies' costs are complexity-driven (Jagersma, 2008). Complexity can be categorised as either necessary or unnecessary. Necessary complexity is what customers are willing to pay for that leads to significant competitive advantages, while unnecessary complexity does not provide enough benefits to cover the associated costs (Serdarasan, 2013; Wilson & Perumal, 2009). Excessive complexity has been shown to decrease a company's competitiveness and business performance (Gilbert et al., 2007; Ho & Tang, 1998) by increasing costs and delivery lead times and by decreasing operational performance and process flexibility (Mariotti, 2008; Trattner, 2019). Furthermore, increasing complexity can cause difficulties in forecasting, can decrease brand value and can increase supplier costs (Quelch & Kenny, 1995). A survey of 255 senior executives showed that product variety did not lead to increased profitability but, instead, created difficulties for customers and employees (Mocker & Ross, 2017).

The challenge of managing complexity is a topic prioritised by top industry managers. According to the results of a survey of more than 100 companies operating in more than 10 industrial sectors, 84% of the respondents viewed complexity as a key cost factor and agreed that understanding this complexity was necessary (Kearney, 2009). Meanwhile, the results of a survey of more than 1,500 CEOs revealed that the CEOs viewed complexity as one of the biggest challenges that companies face (IBM, 2010). Moreover, the findings from a recent survey of 30 global industrial companies demonstrated that 72% of companies conducted ongoing activities to reduce complexity, but 92% of them experienced increasing complexity (CPC, 2019).

Complexity management has been researched in depth by both academics and practitioners. The topic is discussed in numerous doctoral dissertations (Götzfried, 2013; Marti, 2007; Myrodia, 2016; Staśkiewicz, 2022; Trattner, 2019; Webb, 2011) and in journal articles (Bozarth et al., 2009; Choi & Krause, 2006; Closs et al., 2008; Escobar-Saldívar et al., 2008; Hvam et al., 2019; Jacobs & Swink, 2011; Myrodia et al., 2021; Perona & Miragliotta, 2004; Scavarda et al., 2010; Serdarasan, 2013; Van Iwaarden & Van Der Wiele, 2012; Ward et al., 2010). Additionally, several practitioner books have been published on the subject (George & Wilson, 2004; Mariotti, 2008; Wilson & Perumal, 2009).

When managing and reducing complexity in manufacturing companies, the purpose is usually to identify unprofitable complexity or areas of potential cost optimisation. However, this reduced complexity can potentially impact companies' ability to satisfy their customers' needs. Within the academic literature, much work has been done to identify ways to manage and reduce complexity in manufacturing companies (Choi & Krause, 2006; Haug et al., 2013; Lindemann et al., 2010; Meyer & Lehnerd, 2011; Mortensen et al., 2010; Yang et al., 2008; Zheng et al., 2018). However, these studies fail to ensure that the complexity of the company is reduced in a way that minimises any negative impact on future business with existing customers. Therefore, methods are needed to outline ways to manage and reduce complexity while ensuring sufficiently broad value propositions that can satisfy the needs of the most important customers in profitable ways.

Several methods have been proposed to identify and reduce non-value adding product variety (Escobar-Saldívar et al., 2008; Flapper et al., 2010; Hvam et al., 2019; Myrodia & Hvam, 2014;

Staśkiewicz et al., 2022). However, these methods, to a large extent, fail to consider minimising the loss of business from existing customers that results from the reduced product variety. This points to the need for methods to reduce product variety in manufacturing companies while protecting the future business of existing customers.

However, product variety is not a firm's only source of complexity management issues: product-related services also contribute to complexity management concerns. Specifically, a significant part of the value proposition of manufacturing companies today is provided through product-related services (Vandermerwe & Rada, 1988). The cost of providing these services is significant and can, therefore, heavily impact the profitability of individual orders. Therefore, methods are needed to guide the management of product-related service complexity in manufacturing companies while protecting the future business of existing customers.

Product delivery is the most fundamental product-related service provided by manufacturing companies. A common metric to assess the quality of this service in on-time delivery (OTD) performance (Forslund & Jonsson, 2007). However, OTD can be quantified in numerous ways, and the literature lacks a consensus regarding the most appropriate way to approach this task. This situation is further complicated by the fact that customers today are becoming more heterogeneous and have begun demanding customised solutions (Jacobs & Swink, 2011; Quelch & Kenny, 1995; Stäblein et al., 2011; Ulrich, 2006). To accurately assess OTD performance, a quantification method is needed that includes the individual and specific delivery requirements of each customer. This indicates the need to explore on-time delivery performance measurement system designs that more accurately assess the OTD of heterogenous groups of customers. These insights then can be exploited to identify potential areas of improvement, to increase future business with existing customers and to improve the management of product service delivery variety.

Thus, this thesis was intended to generate knowledge on the methods by which manufacturing companies can manage and reduce product complexity and product-related service complexity while protecting the future business of existing customers. The following section presents the questions that guided this research project.

1.2 Research aims and research questions

The objective of this research was to generate knowledge on how manufacturing companies can manage and reduce product complexity and product-related complexity while protecting the future business of existing customers. The research involved an industrial research project; therefore, its purpose was twofold: to address the needs of an industrial research partner and to explore relevant gaps in the academic literature.

Two research questions (RQs) were formulated to guide this research. Reducing product variety in manufacturing companies can negatively impact a company's ability to satisfy the needs of its existing customers, as such reductions cut down on the variety of products offered to these customers. Hence, the first RQ guided the research to explore existing methods for managing product variety and to extend these methods to include ways to protect the future business of existing customers.

RQ1: How can manufacturing companies manage and reduce product variety while protecting the future business of existing customers?

Today, a significant part of the value proposition of manufacturing companies is provided through product-related services. Product-related services are costly and add significant levels of complexity that companies need to manage and control. Therefore, the second RQ guided the research to explore ways to manage product-related service complexity while ensuring profitable and satisfactory customer relations. An extended focus was placed on product delivery because this is the most fundamental and complex product-related service provided by manufacturing companies and because of the lack of clarity in the literature on methods for measuring delivery performance. Thus, the second RQ guided the research to explore ways to design on-time delivery performance measurement systems to more accurately assess the OTD service provided to heterogenous groups of customers, the results of which may help to identify potential areas of improvement, increase future business with existing customers and improve the management of product service delivery variety.

RQ2: How can manufacturing companies manage and reduce product-related service variety while protecting the future business of existing customers?

1.3 Domain limitations

The research was conducted in collaboration with a Danish manufacturer of high-quality plastic products, hereinafter referred to by the pseudonym ‘plastic company’. The studies presented in the thesis explored the challenges faced by the plastic company related to managing product and product-related service variety while minimising consequential negative impacts on the future business of existing customers. Although the focus of the thesis is on the practical needs of the company engaged in the industrial collaboration, the challenges addressed are common to manufacturing companies in general, so the conclusions can be applied in the general context of manufacturing companies.

1.4 Structure of this thesis

In the following section, the theoretical background of the constructs used in the thesis is presented (Section 2), followed by a description of the case-based research design used in the thesis (Section 3). In Section 4, ways for manufacturing companies to manage and reduce product variety while protecting the future business of existing customers are explored and discussed, thus answering RQ1. Similarly, Section 5 explores ways for manufacturing companies to manage and reduce product-related service variety, this answering RQ2. Lastly, Section 6 and 7 present the discussion and conclusions of the thesis.

2 Theoretical background

This section presents the theoretical lenses used to define and explain the concepts of interest in this PhD thesis. These concepts include complexity management and the related dimensions of complexity; the importance, benefits and various approaches for product variety rationalisation; the definition and approaches to managing product-related service variety; and the importance, challenges and potential of product delivery management. The identified gaps in the existing research are discussed in detail and the RQs are answered in section 4 and 5.

2.1 Complexity management

Complexity management is a multifaceted field based on contributions from various domains, including systems theory (Simon, 1996), organisational theory (Child, 1972; Daft, 1998), product design theory (Griffin, 1997; Lindemann et al., 2009; Novak & Eppinger, 2001) and operations management (Bozarth et al., 2009; Jacobs & Swink, 2011; Macduffie et al., 1996). The concept of complexity has been defined in several ways; however, some similarities exist among those definitions. Overall, 'a system or object can be deemed to be complex if it is made up of a multitude of diverse, interrelated elements' (Jacobs & Swink, 2011). Practitioners have explained the nature of complexity as comprising three distinct dimensions – products, processes and organisations – and have argued that complexity exists at the interceptions of these dimensions (Wilson & Perumal, 2009). This is illustrated in Figure 2.1

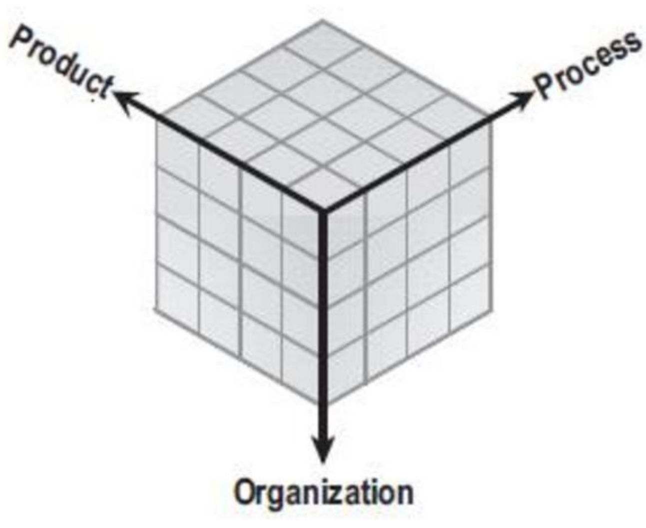


Figure 2.1 - The complexity cube (adapted from Wilson and Perumal, 2009)

Product complexity describes the variety of and within the products or services that companies offer to customers, while process complexity relates to the number of processes, process steps, handoffs and other elements involved in executing and delivering the products of a company (Wilson & Perumal, 2009). Organisational complexity encompasses the number of facilities, assets, functional entities, organisational units, systems and other components involved in executing the processes of a company (Wilson & Perumal, 2009). The research for this thesis focused on the complexity that is created at the intersection of the product and process dimensions. The conditions experienced by companies due to this type of complexity include the following: a high number of unprofitable products, negatively impacting the company earnings; high levels of inventory, consuming working capital; product shortages, leading to lost sales; product surpluses, resulting in markdowns and waste; long lead times, triggering customer frustration; frequent production changeovers, leading to an erosion of product capacity; subpar levels of delivery service, customer service and quality levels; and the feeling that every action leads to negative reactions in other parts of the operation (Wilson & Perumal, 2009). The results of a survey involving 195 industrial companies in the United States showed that product-process complexity has the most significant negative impact on performance (Mocker et al., 2014).

The product complexity dimension comprises the variety of both products and services (Wilson & Perumal, 2009). Throughout this research, the term '*product variety*' is used to refer to the complexity related to physical products, while '*product-related service variety*' is used to refer to the complexity related to the embedded services that are provided by companies to help customers manage a product during its useful lifetime (Gaiardelli et al., 2014).

The literature cites multiple definitions for product variety (Trattner et al., 2019). For example, product variety has been defined by the number of components in production (Berry & Cooper, 1999; Blackenfelt, 2001; Macduffie et al., 1996), the number of finished goods or products in a firm (ElMaraghy et al., 2013; Pil & Holweg, 2004; Stäblein et al., 2011) and the number of product variants in product offerings – in other words, the number of stock keep units, or SKUs (Kampen & Donk, 2011; Pine et al., 1993). In this research, product variety is defined as the number of end product variants that a manufacturer offers to its customers (Myrodia et al., 2021).

Manufacturing companies are moving from primarily selling physical products to offering increasing arrays of services to support these products (Guillon et al., 2021). In this context, supporting services can be described according to three classifications: (1) result-oriented services, where the provider and buyer agree on a result without defining the products to be used; (2) use-oriented services, where the buyer purchases the right to use a physical product while it is still owned by the provider; and (3) product-oriented services, which are sold in addition to a physical product with the latter still considered the main offering (Tukker, 2004). Product-oriented services can be further split into two subcategories: (1) advice, training and consulting, which focus on both products and processes, and (2) product-related services, which focus on the products (Gaiardelli et al., 2014; Tukker, 2004). In this research, the focus is on product-related service variety, which is defined as the number of product-related service variants that a manufacturer offers to its customers. Examples of such services include maintenance, financing schemes, takeback agreements, product transportation, installation and providing repairs and spare parts (Gaiardelli et al., 2014; Guillon et al., 2021; Lenfle & Midler, 2009; Tukker, 2004).

As is the case with product variety, the literature defines the concept of process variety in various ways. Definitions include the 'degree to which a process is difficult to understand, analyse and explain' (Cardoso, 2005, pp. 202) and 'a measure of how product variety can complicate the production process' (Samy & Elmaraghy, 2012, pp. 815). Sivadasan et al. (2002) identified two types of supply chain complexity: structural complexity, which rises with increases in the number of products, and operational complexity, which rises as the uncertainty of information and product flows increases. Thus, the complexity of business processes is directly related to the level of product complexity. When product variety increases, product complexity grows, negatively impacting operational performance as processes become more challenging to execute (Staśkiewicz, 2022). Moreover, excessive business process variety is associated with increased process and supplier diversity (Sousa & Voss, 2007), increased levels of complexity in manufacturing and logistics systems (Chryssolouris et al., 2013), complex production planning and scheduling (Chryssolouris et al., 2013), increased inventory (Khatri & Brown, 2010) and increased fixed asset investments (Khatri & Brown, 2010).

2.2 Product variety rationalisation

Studies have shown that increased product variety can have multiple effects on operational performance (Trattner, 2019), including increased inventory level and back orders (de Groote & Yücesan, 2011), longer lead times (Thonemann & Bradley, 2002), more complex sourcing

(ElMaraghy et al., 2013), increased operational learning curves (ElMaraghy et al., 2013) and increased defect rates (Ton & Raman, 2010). Consequently, effective management of product variety has proven to be key to gaining a competitive advantage (Götzfried, 2013; Ramdas, 2003).

The literature does not identify a dominant strategy for effectively and competitively managing product variety (Ulrich, 2006). However, such strategies usually involve balancing the need to meet market demands while maintaining scale economics in the value chain (Lancaster, 1990). The operations management and marketing literature approach product variety rationalisation decisions in different ways: operations management research focuses on identifying and terminating unprofitable, slow-moving, low-volume products to reduce their deteriorating impact on operational performance (Kearney, 2009; Rigby, 2017; Thiel et al., 2017; Wilson & Perumal, 2009), while marketing research focuses on adjusting product assortments by means of product portfolio optimisation and substitution to increase sales and market share (Berry & Cooper, 1999; Götzfried, 2013; Silveira, 1998). Frameworks and procedures for managing variety that incorporate both marketing and operations management perspectives have been published in the academic and practitioner literature (Escobar-Saldívar et al., 2008; Hvam et al., 2019; Mariotti, 2008; Myrodia & Hvam, 2014; Perumal & Wilson, 2017; Staśkiewicz et al., 2022).

One noteworthy procedure, proposed by Hvam et al. (2019), was intended to assist companies in product variety rationalisation through the calculation and allocation of complexity costs (i.e. costs that vary based on product variants but are not identified or allocated to products in traditional product costing methods [Götzfried, 2013; Hansen et al., 2012; Hvam et al., 2019; Ramdas, 2003; Trattner, 2019; Wilson & Perumal, 2009]). The procedure involves the following five steps:

1. Define the scope of products and processes to be included in the analysis.
2. Rate products into A, B and C categories based on a double Pareto analysis of their turnover and contribution margin.
3. Identify and quantify the most significant complexity cost factors.
4. Identify and quantify initiatives to reduce complexity costs.
5. Evaluate and prioritise complexity cost reduction initiatives.

This procedure is useful because the flexible, step-by-step guide can be applied in various industrial contexts. The process of rating product variants into A, B and C categories according to financial performance and then using this classification to guide product variety rationalisation decisions is especially interesting and useful.

However, the reduction in the product portfolio that results from reducing product variety might negatively impact a company's ability to satisfy the needs of its existing customers, which, in turn, may lead to lost revenue if the impact manifests in a customer's decision to do business with other suppliers. I term this phenomenon 'linked revenue', which is the revenue lost when customers stop buying certain product variants they purchased previously after other product variants that they also purchased previously are terminated (Andersen, Andersson, et al., 2023). Existing frameworks and procedures fail to provide solutions that consider ways to minimise the negative impact of the reduced product variety offered on the future business of existing customers. Descriptions of a few methods touch on the objective but do not provide the necessary details to understand ways to achieve it. Myrodia and Hvam (2014) expressed concern about this gap in the literature and briefly highlighted the usefulness of considering linked revenue when conducting product variety rationalisation projects. Nevertheless, in their subsequent case study, the impact of linked revenue was not considered. Similarly, Flapper et al. (2010) developed a conceptual model to identify the optimal product assortment based on the assumption that customers will only place orders if all their desired products can be delivered on time. This approach, while interesting, does not provide companies with an easy-to-follow procedure for identifying and reducing unprofitable product variety while minimising the turnover lost from profitable customers. This identified gap in the existing frameworks and procedures led to the formulation of RQ1, which seeks to uncover ways that manufacturing companies can manage and reduce product variety while protecting the future business of existing customers.

2.3 Product-related service variety

A significant part of the value proposition offered by modern manufacturing companies is provided through product-related services (Vandermerwe & Rada, 1988). While offering these services can be highly profitable, many companies struggle to determine which services to offer and how they should be defined (Cusumano et al., 2010; Raja et al., 2018). Additionally, adopting servitisation strategies requires companies to find new ways to organise their resources to provide services efficiently and effectively (Hakanen et al., 2017).

Engineer-to-order (ETO) product development and sales processes face challenges similar to those involved in the creation of customer-specific product-related services, given the uniqueness of each product. To address these challenges, the companies involved widely use product configurators. The literature reports on a multitude of benefits obtained from using product configurators, including shorter specification lead times (Ardissono et al., 2003; Forza & Salvador, 2002a, 2002b; Haug et al., 2011; Hvam et al., 2004, 2006), reduced product delivery lead times (Ardissono et al., 2003; Haug et al., 2011; Hvam et al., 2006), reduced person hours (Ardissono et al., 2003; Forza & Salvador, 2002a, 2002b; Hvam et al., 2004), increased quality of product information and specifications (Ardissono et al., 2003; Forza & Salvador, 2002a, 2002b, 2008; Haug et al., 2011; Hvam et al., 2004), improved product quality (Trentin et al., 2012), improved on-time delivery performance (Forza & Salvador, 2002a, 2002b; Tenhiälä & Ketokivi, 2012) and lower production costs (Hvam et al., 2006).

Several approaches for the development of product configurators have been proposed (Forza & Salvador, 2006; Haug et al., 2012, 2019; Hvam et al., 2006, 2008a); however, these traditionally only include physical products. Mueller et al. (2022) are the exceptions: they established and tested an approach to developing a service configurator for commissioning complex ETO products. However, the issues and challenges involved in developing a configurator for product-related services differ significantly from those involved in the development of configurators for complex commissioning services, which relate to mapping existing product-related services and evaluating which to include in the scope of the configurator. Furthermore, the cost and availability of product-related services are mainly governed by the characteristics of the related specific physical products being sold and the customers to whom they are sold (Guillon et al., 2021). A service configurator for product-related services should, therefore, include a systematic process for defining the constraints required to avoid impossible or undesirable product-customer-service combinations and for developing customised cost models to accurately assess the cost of product-related service variants according to the characteristics of the selected products and the desired customers. If companies are not able to accurately calculate the costs of providing product-related services, they risk underestimating the actual cost of providing such services and committing to customer contracts that are ultimately unprofitable. Alternatively, they risk overestimating the cost of providing these services, thereby demanding non-competitive prices from the market and potentially losing business (Benedettini et al., 2015; Raja et al., 2018).

This identified gap led to the formulation of RQ2, which seeks to uncover ways that manufacturing companies can manage and reduce product-related service variety while protecting the future business of existing customers.

2.4 Managing the product delivery service

The most fundamental and complex product-related service provided by manufacturing companies is *product delivery*. Various metrics are used to assess the performance of product delivery services (Peng & Lu, 2017). Measuring delivery performance, however, is a complex task because multiple aspects must be considered. This is exemplified in the variety of ways that delivery performance has been defined in the literature. Ulaga and Eggert (2006), for example, identified three dimensions of delivery performance: (1) on-time delivery, which is the ability of a supplier to consistently meet delivery schedules; (2) delivery flexibility, which is the ability to adjust to changes in delivery schedules because of spikes in demand or changes in the product mix; and (3) delivery accuracy, which is the ability to deliver the correct parts and to do so consistently. Peng and Lu (2017) divided delivery performance into two dimensions – reliability and speed – which they further categorised into on-time delivery rate, early delivery inaccuracy, late delivery inaccuracy and delivery speed.

The focus of this research is on-time delivery (OTD) performance, which reflects the percentage of orders delivered on time. The literature identifies various benefits obtained by improving OTD performance, including the reduced likelihood of returns (Rao et al., 2014), ability to charge higher prices (Mewborn et al., 2014), increased transaction quantity and unit price (Peng & Lu, 2017) and supplying a leading indicator for future sales (Nagar & Rajan, 2001). Thus, OTD is a significant driver of improvement initiatives within a company. Coronado et al. (2017) found, for example, that OTD performance is among the most important factors affecting manufacturing technology selections within UK composite material supply chains. Furthermore, the literature indicates that a responsive planning and control system is the most important facilitator of good delivery performance (Lane & Szwejczewski, 2000) and that companies can positively influence the OTD performance of their key suppliers through socialisation efforts (Cadden et al., 2020).

The selection of metrics used to quantify OTD performance directly impacts what is being measured (Forslund & Jonsson, 2007, 2010). For example, to quantify OTD, the time of delivery is compared with what Forslund and Jonsson (2007) referred to as the *comparison date*. The definition of the comparison date can vary. For instance, it can be the date agreed upon and confirmed by the supplier, or it can be the date originally requested by the customer. Using the supplier-confirmed delivery date to quantify OTD provides a measure of how well a supplier manages to deliver on what it has promised, while using the customer's requested delivery date evaluates how well a supplier can comply with the temporal needs of its customers (Forslund & Jonsson, 2010; Knoblich et al., 2015). Quantifying OTD performance using the supplier-confirmed delivery date as the comparison date produces what hereinafter is referred to as the supplier-confirmed on-time delivery (SC-OTD) rate (Andersen, Hvam, & Forza, 2023). When using the customer's requested delivery date, OTD is defined as the customer-perceived on-time delivery (CP-OTD) rate (Andersen, Hvam, & Forza, 2023). The word 'perceived' is introduced because this indicator recalls the judgemental comparison that customers consciously or unconsciously make between their temporal need (expressed through their order request) and how well it has been satisfied.

When quantifying OTD performance, the *time unit* or *delivery time window* defines the period during which an order must be delivered for the delivery to be considered on time (Forslund & Jonsson, 2007). As customers are becoming more heterogenous (Stäblein et al., 2011), different customers may have different degrees of delivery sensitivity, so they may attribute different meanings to OTD. For example, for some customers, an order line that is delivered one day prior to the promised date is considered on time, while others may not tolerate early deliveries. Consequently, to accurately quantify OTD performance, different delivery windows should be defined to reflect the heterogenous delivery requirements of different customers.

However, research efforts to explore the benefits of using multiple delivery windows are limited Additionally, measuring and managing CP-OTD has received limited attention from academic research, even though measuring CP-OTD correctly and gaining a clear understanding of the benefits that can be drawn from doing so is essential. Therefore, an extended focus of this thesis was to explore whether the addition of CP-OTD considerations and the use of multiple delivery time windows in delivery performance measurement systems can increase the accuracy with which manufacturing companies assess the delivery performance of heterogenous customers and, if so how this increased accuracy can be exploited to improve the management of product delivery services while protecting (and growing) the future business of existing customers.

2.5 Summary and identified research gaps

Studies have shown that increased product variety negatively impacts operational performance in numerous ways (de Groote & Yücesan, 2011; ElMaraghy et al., 2013; Thonemann & Bradley, 2002; Ton & Raman, 2010; Trattner, 2019) and that the effective management of product variety is, therefore, a key to gaining a competitive advantage (Götzfried, 2013; Ramdas, 2003). Various frameworks and procedures for managing and reducing product variety have been proposed (Escobar-Saldívar et al., 2008; Hvam et al., 2019; Mariotti, 2008; Myrodia & Hvam, 2014; Perumal & Wilson, 2017; Staśkiewicz et al., 2022). However, the proposed designs fail to provide solutions that consider ways to minimise the negative impact that the reduction in product variety has on the future business of existing customers.

A significant part of the value proposition and complexity of manufacturing companies relates to the product-related services they provide (Vandermerwe & Rada, 1988). ETO product development and sales processes face challenges similar to those involved in the creation of customer-specific product-related services due to the uniqueness of each product. ETO companies use configurators extensively as a tool to address these challenges. However, existing approaches to developing configurators (Forza & Salvador, 2006; Haug et al., 2012, 2019; Hvam et al., 2006, 2008a; Mueller et al., 2022) do not address some of the distinct obstacles faced in the management of product-related services.

Product delivery is the most fundamental product-related services provided by manufacturing companies. The literature mentions significant benefits to be obtained by improving delivery performance (Mewborn et al., 2014; Nagar & Rajan, 2001; Peng & Lu, 2017; Rao et al., 2014). Evaluating the timeliness of orders according to the delivery date confirmed by the supplier provides a measure of how well a supplier manages to deliver on what it has promised, whereas using the delivery date requested by the customer to evaluate the timeliness of orders provides a measure of how well a supplier manages to comply with customers' needs (Forslund & Jonsson, 2010; Knoblich et al., 2015). These are both useful measures; however, limited attention has been paid to the latter in the literature. Moreover, with customers growing increasingly heterogenous and demanding (Stäblein et al., 2011), the need to use delivery time windows that reflect customers' individual needs when evaluating the timeliness of orders has gained importance.

However, using multiple delivery time windows to quantify OTD is another topic that has received limited attention in the literature.

For these reasons, the following can be argued: (1) a procedure must be developed that guides product variety rationalisation activities while also considering ways to minimise the negative impact of the reduced product variety on the company's ability to meet its existing customers' future needs; (2) a strategy must be established for developing and implementing configurators that addresses the challenges of managing product-related services; and (3) the potential for evaluating the timeliness of deliveries using customer-requested delivery dates and multiple delivery time windows must be explored to reveal insights into ways for manufacturing companies to better manage product delivery services.

3 Research design

The research design of the thesis is presented in the following sections in order to begin the layered conversation on the management of complexity in manufacturing companies.

3.1 Philosophical position of this thesis

Research philosophy describes the assumptions about how scientific knowledge should be produced. These assumptions regulate the development of knowledge and the nature of that knowledge by describing research strategies and the research methods that support these (Saunders et al., 2012). Research philosophy is based on both ontological (the nature of reality) and epistemological (the nature of knowledge) assumptions, that influence the ways in which researchers view the relationship between knowledge and the processes by which knowledge is developed (Saunders et al., 2012).

Ontology is a system of beliefs that describe researchers' perception of what a fact is. Within management and business research, two extremes of ontological positions exist, objectivism and subjectivism. Objectivism asserts that 'social phenomena and their meanings have an existence that is independent of social actors' (Bryman, 2012, pp. 16-18). Whereas subjectivism asserts that 'social phenomena and their meaning are continually being accomplished by social actors' (Bryman, 2012, pp. 16-18). Epistemology is a system that describes researchers' perception of what constitutes acceptable knowledge in a field of study (Saunders et al., 2012). Within management and business research, two main paradigms within the field of epistemology are positivism and interpretivism. Within positivism, it is emphasised that the objective reality should be gained through observable and measurable facts, meaning that it should not rely on subjective experiences. Within interpretivism, reality is subjective, as all observations and analyses are socially constructed and based on the perceptions of the individual researcher (Saunders et al., 2012). Within the research areas of information systems science and social science, it is argued that these two paradigms are subject to theory-practice inconsistencies between researchers' assumptions, empirical evidence and research practices (Bhaskar, 2011; Fleetwood, 2001; Smith, 2006). These inconsistencies led to the development of critical realism (Bhaskar, 2008). According to this paradigm, there exists a world independent of human actors, who, however, do not have full access to this (as it is implicitly assumed by positivism). As opposed to focusing on research data and methods, critical realism instead focuses on the real problem and its original causes (Mingers, 2000).

The foundational philosophy of this thesis is critical realism. For a more in-depth discussion of how the paradigm of critical realism supports the research approaches used by the author's research group at DTU, see the discussion by Haug (2008, pp. 47) and Ladeby (2009, pp. 209-212).

3.2 Research methodology

The purpose of this thesis is to contribute to research by generating scientific knowledge and to practice by providing directions for applying this knowledge (Melnyk & Handfield, 1998). The focus is to generate new knowledge by exploring the management of complexity in manufacturing companies in real-life settings. This is done through case study research by examining the issues of effective management of complexity experienced by an industrial collaboration partner.

Case research is one of the most powerful research methods for acquiring in-depth understanding of phenomena in the field of operations management (Voss et al., 2002), and its application in critical realist studies has been encouraged (Wynn & Williams, 2012). A case study is defined as one that 'that investigates a contemporary phenomenon (the 'case') in depth and in its real-world context, especially when the boundaries between phenomenon and context may not be clearly evident' (Yin, 2018). The selection of the case study method can be justified by multiple reasons. It is suitable to apply case research to phenomenon-driven research that study unexplored phenomena (Eisenhardt & Graebner, 2007) and it is suitable for answering "how" and "why" research questions (Yin, 2018). Through case research, it is possible to study the units of analysis in-depth, over time, in real time and in natural settings (Yin, 2018). Furthermore, both primary and secondary data sources of data can be analysed, thus resulting in rich empirical discussions (Yin, 2018).

Case research, however, suffer from limitations related to generalisability. Single-case studies are able to describe phenomena in rich detail and facilitate broad explorations of research questions. However, the use of multiple cases results in more robust, testable and generalisable results (Eisenhardt & Graebner, 2007). However, it can be argued that the pursuit of generalisability in research kills knowledge of the particular (van Aken et al., 2016). Yin (2018, pp. 21) also argue that the results of case studies can be generalised to theoretical propositions and not to populations, as the goal is to expand and generalise theories (analytic generalisation) and not to extrapolate probabilities (statistical generalisation). To address these limitations, one of the studies presented in this thesis uses two separate case studies to strengthen the robustness and generalisability of the results. The remaining studies employ single-case studies conducted in collaboration with the industrial collaboration partner. In these case studies, the generalisability is strengthened by the strategic selection of cases to enable the collection of the greatest possible amount of information about the phenomena (Patton, 2015). Additionally, each study contains discussions of the potential and limitations regarding the generalisability of the results achieved.

The research process of this thesis began with semi-structured interviews with human actors and observations of the environment and situation within the collaborating partner company. The purpose of these initial analyses was to gain an understand of the specific challenges related to the management of complexity faced by the company. This was followed by literatures studies to obtain a basic understand of the phenomenon of interest, including existing methods, frameworks and procedures for managing complexity in manufacturing companies. Next, semi-structured interviews were conducted to identify sources of data, including both key persons and IT systems. Empirical data was collated and analysed to confirm the observations made by the human actors and to thereby define the practical issues and challenges caused by the phenomenon of interest. Finally, more targeted literature searches were conducted to identify existing research addressing specific issues and challenges caused by the phenomenon of interest. It was revealed that the challenge of managing complexity in the collaborating partner company was tied to two distinct types of variety, product variety and product-related service variety. Consequently, two research questions were formulated to guide the research to address these two distinct challenges. Table 3.1 provides and overview of the research method applied in each of the four studies presented in this thesis. This is further elaborated upon in the following sections.

Table 3.1 - Research methods applied in the studies of thesis

RQ	Study	Title	Research objective	Research Method
RQ1	Study A	A Procedure for Product Variety Reduction That Considers Linked Revenue	Developing and testing a procedure for product variety reduction that minimises the negative impact on the future business of existing customers	Single-case study
	Study B	The role of linked revenue in product variety reduction: A procedure and two case studies	Improvement and additional testing of the procedure for product variety reduction that minimises the negative impact on the future business existing of customers	Multiple-case study
RQ2	Study C	An approach for the development and implementation of configurators for product-related services	Developing and testing an approach for the development and implementation of configurators for product-related services	Single-case study
	Study D	On-time delivery performance: Motivations for including customer requested date as comparison date	Testing the benefits of enhancing product delivery performance measurement systems with customer-requested date and multiple customer-dependant delivery time windows	Systematic literature review and single-case study

Study A and Study B address RQ1. In these studies, a procedure for the reduction of product variety that considers linked revenue is developed and tested. Study A is a conference article that presents the proposed procedure and tests its usefulness in a single-case study. Due to the limited length of the conference paper, the procedure and case study is only briefly presented. Study B presents a refined and more comprehensive version of Study A, including more details and reflections and an additional case study conducted in a separate flow manufacturing company. This multiple-case study approach allows for the generation of information about the differences and similarities across the two cases and strengthens generalisability (Yin, 2018). Data was collected in two phases. During the first phase, data were continuously collected as part of the projects. These data were used to understand the processes related to and the effects of applying each step of the proposed procedure. During the second phase, data was collected regarding the overall impacts of implementing the procedure and the general feasibility of the procedure. Both quantitative and qualitative data was collected and analysed. Quantitative data was collected through semi-structured interviews with key stakeholders in the case companies. Additionally, quantitative analyses were conducted to explore the value of the proposed procedure is each case. The results achieved in each case study are compared and discussed.

Study C and Study D address RQ2. In Study C, an approach for the development and implementation of configurators for product-related services is proposed and tested in a single-case study. The case study was split into two parts. The purpose of the first part was to test the usefulness of the proposed approach in an industrial setting. The case study was carried out over a nine-month period, during which data from workshops and meetings were collected and analysed. The purpose of the second part was to assess the benefits gained by using the developed configurator when compared with the existing manual specification process in the case company. Quantitative analyses were conducted based on real order data that was collected, validated and used to test the compare the performances before and after the implementation of the configurator. Additionally, qualitative data was collected through semi-structured interviews with company experts. The purpose of these interviews was both to confirm the validity of the quantitative tests and to identify additional benefits gained from using the developed configurator.

In Study D, a systematic literature review (Tranfield et al., 2003) was conducted to synthesise how OTD is defined in academic literature with a subsequently focus on how CP-OTD has been used as a performance measure. A sample of 182 relevant articles was identified and analysed. This was followed by a single-case study to explore the benefits to be gained from enhancing delivery performance measurement systems with CP-PTD and multiple customer-dependant delivery time windows. A total of 47,323 sales order lines from a 12-month period were used to quantify OTD rates by using various OTD metrics. Due to a lack of fundamental understand of the topic that was explored and due to the difficulties associated with collecting and controlling the required data, an in-depth single-case study approach was preferred to using a broader, less in-depth multiple-case study approach (Shurrab et al., 2022). Furthermore, by presenting the results in the context of a single-case study, the results would be easier to comprehend for the reader. Qualitative data was collected through workshops with managers at the case company. At these workshops, the results of the qualitative analyses were reported and discussed and based on this, the following steps of the analyses were defined.

The biases of the researchers should be considered when designing studies and assessing results of research. In the present studies, it is possible that the subjectivity of the studies has been affected by various stakeholders, including supervisors and company representatives. Efforts to avoid these effects were made by posing critical questions and through triangulation of results. The contents and design of the research project was presented at conferences and doctoral seminars, and the findings were submitted to conferences and academic journals to receive external feedback from relevant experts. Thus, the rigour and validity of the research was supported.

3.3 Primary case company: A plastic manufacturer

The case studies of this theses were largely accomplished through collaboration with a Danish manufacturer of high-quality injection moulded plastic products. The company employs approximately 200 workers, reports an annual turnover of 23 million euros and has its main production site in Denmark along with a supporting production site and main distribution centre in central Europe. The company also has distribution centres located in North America and Asia.

In recent years, the plastic company has experienced a rapid increase in product variety, resulting in increasing complexity costs and deteriorating financial and operational performance. The management of the company therefore recognised the need for product variety rationalisation efforts and changes to improve the general management of product variety. In addition to their physical products, the plastic company offers a wide range of product-related services to support their products. These product-related services contribute to a significant part of the value proposition that is offered to customers and is connected with significant costs and complexity. However, at the beginning of the research project, the plastic company had only limited levels of transparency regarding the costs of providing product-related services. Initial analyses showed that the cost related to providing product-related services varied substantially depending on the characteristics of the offering, i.e., the cost of shipping is heavily influenced by the physical dimensions of the products being sold, the geographical location of the customer and the volume of products shipped with each order. This resulted in numerous cases of orders that were assessed as profitable at the time that contracts and price agreements were made with customers, but ultimately turned out to be unprofitable as the cost of providing the product-related services were under-estimated. The low levels of cost transparency also resulted in the risk of over-estimating the costs of product-related services in specific orders, thus leading the plastic company to demand non-competitive prices from the market, resulting in the loss of potential business. The managers of the plastic company therefore recognised the need for more effective management of product-related services and the need for increased cost transparency.

The plastic company services two main segments of customers. The needs of these segments differ significantly. Customers in the first segment (A) generally require high levels of product quality and documentation, are less sensitive to price, provides long-term forecasts, seek to maximise the portion of needs that can be fulfilled by a single supplier and follow a just-in-time (JIT) production model, making them very sensitive to delivery times with a low tolerance for both late and early delivers. Customers in second segment (B) have lower quality requirements, but are more cost-driven and therefore more sensitive to price, place spot orders close to the requested delivery date, are willing to accept additional suppliers to achieve lower prices and are less sensitive to delivery times, especially regarding early deliveries. The characteristics of the two customer segments are summarised in Table 3.2. Managers in the plastic company recognise that serving customers with such different requirements and behaviours is challenging and complex, and that a need exists to improve and differentiate the ways in which these customers are served.

Table 3.2 - Characteristics of main customer segments

Customer characteristics	**Customer segment A**	**Customer segment B**
Quality and documentation requirements	High	Low
Price sensitivity	Low	How
Ordering behaviour	Provides long-term forecasts	Spot orders
Supplier management strategy	Maximises the portion of their needs met by each supplier	Willing to accept additional suppliers to achieve lower prices
Delivery sensitivity	High – does not tolerate early deliveries	Medium – does not mind early deliveries

The plastic company serves more than 1,200 active customers. A relatively limited fraction of these customers contributes to the vast majority of the business in the company. At the beginning of the research projects, it was clear to the managers in the company that it is of vital importance to prioritise the satisfaction of these customer to maintain and grow future business. However, no formal processes or systems were setup to facilitate this prioritisation.

4 How can manufacturing companies manage and reduce product variety while protecting the future business of existing customers?

Evidence has shown that excessive product variety negatively impacts operational performance in numerous ways (de Groote & Yücesan, 2011; ElMaraghy et al., 2013; Thonemann & Bradley, 2002; Ton & Raman, 2010; Trattner, 2019). Therefore, effectively managing product variety is a key to maintaining a competitive advantage (Götzfried, 2013; Ramdas, 2003). Various frameworks and procedures for managing and reducing product variety have been proposed (Escobar-Saldívar et al., 2008; Hvam et al., 2019; Mariotti, 2008; Myrodia & Hvam, 2014; Perumal & Wilson, 2017; Staśkiewicz et al., 2022). Hvam et al. (2019) proposed the use of ABC analyses to classify individual product variants into categories according to Pareto analyses of turnover and contribution margin. Following this approach, A-products are responsible for the top 80% of turnover and contribution margin, products responsible for the next 15% are B-products, and the products responsible for the final 5% of turnover and contribution margin are C-products. This categorisation is then used to guide production rationalisation decisions (Hvam et al., 2019). In addition, conducting a similar ABC analysis on customers enables the study of their purchasing behaviour as well. Figure 4.1 illustrates the turnover of individual A-customers of plastic company divided between A-, B- and C-products for a 12-month period. It becomes apparent that A-customers often purchase C-products. Therefore, if C-products are terminated, due to their individual poor financial performance, this may cause customers to also stop purchasing other products. This phenomenon is termed 'linked revenue', which is the revenue lost when customers stop buying certain product variants they purchased previously after other product variants that they also purchased previously are terminated (Andersen, Andersson, et al., 2023).

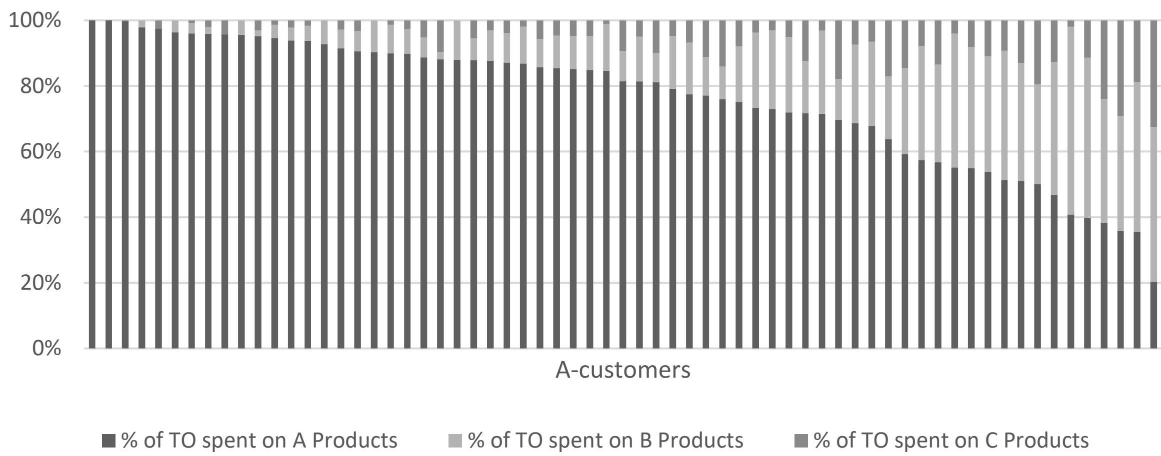


Figure 4.1 - Fraction of turnover spent on A-, B- and C-products by individual A-customers; TO = turnover

Existing frameworks and procedures for managing and reducing product variety fail to consider ways to minimise the negative impact of the reduced product variety on the future business of existing customers. To address this, a product variety reduction procedure that considers linked revenue was developed, which is presented and tested in publications that describe Study A and Study B (see appendix for the full texts of each article).

Study B represents a refined and more comprehensive version of Study A, including an additional case study. Therefore, the results from Study B are presented here. The aim of Study B was to develop and test a procedure for product variety reduction that considers linked revenue. This procedure was inspired by an existing procedure (Hvam et al., 2019). Like the original procedure, the modified procedure was designed to function as a step-by-step guide while being generic enough to be applicable to all manufacturing companies. The general purpose of the procedure is to identify and systematically evaluate unprofitable product variety, to assess the impact of terminating this variety and then, based on these appraisals, to make decisions regarding which product variants to terminate. However, the modified procedure also seeks to assess the potential negative impact that the resulting reduction in product variety will have on future business with existing customers and to consider these insights when deciding which product variants to terminate. Furthermore, stakeholders in departments that are typically responsible for internal resistance towards product variety reduction initiatives are directly involved in the product variety reduction procedure to reduce that internal resistance. Moreover, the procedure is relatively simple and can be implemented quickly because the only data needed are readily available in most manufacturing companies and only limited expert knowledge regarding product characteristics and market requirements is required. The feasibility and usefulness of the proposed procedure was tested in two case studies, the first conducted at the site of the plastic company and the other conducted at another Danish manufacturing company operating in the chemical industry.

4.1 The proposed procedure for product variety reduction that considers linked revenue

The purpose of the first step in this product variety reduction procedure is to define which products to include in the scope of the analysis. The included products should be comparable in the ways in which they are manufactured and handled by the company (Hvam et al., 2019). At the same time, the aggregation level upon which the customer evaluations will be based is identified, and a decision is made regarding whether to evaluate customers served at multiple locations in different countries and regions as one entity or as several entities. Additionally, the appropriate period of sales order data on which to base the analyses is identified. A minimum of twelve months' worth of sales order data is recommended to account for fluctuations due to seasonality. Moreover, using data from an extended period reduces the risk of overlooking infrequent customer–product transactions; however, it also introduces the risk of encompassing changes in customers' purchasing behaviours.

Similar to the procedure proposed by Hvam et al. (2019), after defining the scope of the examination, double ABC analyses are conducted for product variants and customers. Here, each product variant and individual customer is divided into categories based on their individual turnover and contribution margin values for the period. Each product variant and customer is awarded two ratings, one for turnover and one for contribution margin. The identification and quantification of complexity cost factors (CCFs) to increase the cost transparency of individual product variants is a central part of the procedure proposed by Hvam et al. (2019). If such cost allocation analyses have been conducted, then the complexity adjusted contribution margin (CM2) should be used as the basis of the ABC analyses. However, if no such cost allocation analyses have been conducted, then the ABC analyses can be based on the traditional contribution margin extracted directly from an enterprise resource planning (ERP) system. The products and customers responsible for the top 80% of turnover and contribution margin are categorised as A-products/customers, those responsible for the next 15% are identified as B-products/customers, and the products and customers responsible for the final 5% of turnover and contribution margin are considered C-products/customers. If a product variant or customer is given two different ratings, the final rating will be the lower of the two. This logic is illustrated in Table 4.1. The outcome of this first step is a list of C-products that are to be further analysed and evaluated for termination, as well as a list of all customers categorised as either A, B or C.

Table 4.1 - Logic for ABC categorisation

TO[1] category	CM[1] category	Final category
A	A	A
A	B	B
A	C	C
B	A	B
B	B	B
B	C	C
C	A	C
C	B	C
C	C	C
1) turnover; 2) contribution margin		

The purpose of the second step of the procedure is to define the existing customers whose business should be protected by considering linked revenue. This includes analysing the various customer groups served by the company to determine which groups are prone to being associated with linked revenue, as well as identifying currently unprofitable customers that are expected to become profitable in the future. The linked revenue of these strategic customers then is marked for protection. Lastly, protecting the linked revenue of A-customers is always recommended. However, whether to also protect the linked revenue of B-customers depends on the situation in the company and on the willingness of the company's managers to put the linked revenue of these customers at risk.

The purpose of the third step in this product variety reduction procedure is to identify unprofitable product variants that can be terminated without risking the linked revenue of the customers marked for protection identified in the previous step. This is done by analysing sales order data from the period defined in Step 1. The goal is to identify all C-products that have never been purchased by any of the customers whose linked revenue should be protected. The outcome is a list of products that will be further evaluated for termination in the following steps.

Additional reasons may exist for protecting unprofitable products from termination. The purpose of the fourth step is to identify these reasons and to determine which specific products should be protected for these reasons.

The purpose of the fifth step is to quantify the expected impact of various termination scenarios. These insights are to be used to decide which product variants to ultimately nominate for termination. Products are evaluated for termination based on their turnover and contribution margin ratio (CMR). The logic underlying this approach is that the higher the turnover of a product, the larger its potential for becoming profitable through price increases or cost reductions, thereby making a smaller CMR acceptable. Conversely, even if a product has a high CMR, if its turnover is low, it will still not cover its expenses. Therefore, products with low rates of turnover need a higher CMR to be protected from termination.

As the next step of the procedure, several termination scenarios are then created that systematically evaluate each individual product variant according to its turnover and CMR. Specifically, product variants are divided into groups according to their turnover values. These groups must be defined so that the product variants in each group are homogenous enough to be evaluated according to the same criteria. Moreover, each scenario defines the minimum CMR required by each turnover group for products to qualify to be protected from pruning. Figure 4.2 illustrates this concept by evaluating product variants according to three termination scenarios. Product X has a low turnover rate, meaning that even with an ample CMR, it will be terminated in all three scenarios. Product Y has a CMR equal to that of Product X but has a much higher turnover value. Therefore, Product Y will not be terminated in any of the three scenarios. Lastly, Product Z has an acceptably high turnover value, but a low CMR. Consequently, it will only be terminated in Scenario 1, which is the most conservative scenario.

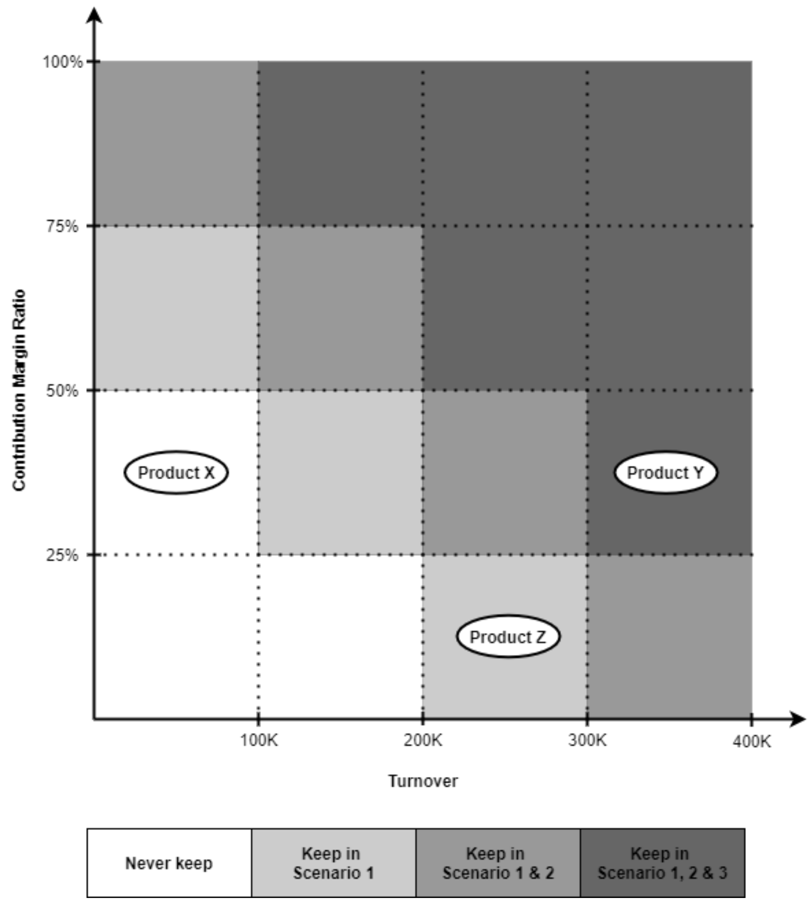


Figure 4.2 - Evaluation of product variants according to turnover and contribution margin ratio for three scenarios (Andersen, Andersson, et al., 2023)

Next, the specific product variants to be terminated according to each termination scenario are identified, and then the expected impact of terminating those products is quantified by calculating the production capacity that would be released if the products were no longer produced and then calculating the expected value to be gained by using that released production capacity to instead manufacture A-products for the company to sell. Finally, the impact of each termination scenario is presented to a steering committee that decides the scenario with which to continue. This results in a list of C-products nominated for termination.

The purpose of the sixth step of the procedure is to collect feedback from customer account managers. Personalised overviews are created for each affected customer account manager. These overviews contain information regarding customers who have historically purchased any of the products nominated for termination, ideally with the specific volumes sold indicated. If the customer account managers believe any of the products should be protected from termination, they are asked to provide detailed reasons to support their position. As part of this step, a deadline for submitting such feedback should be set and clearly communicated to the customer account managers.

The purpose of the seventh and final step of this product variety reduction procedure is to evaluate the collected information and then finalise decisions on which product variants to terminate. The result is a list of specific product variants to be terminated.

4.2 Testing the proposed procedure in two case studies

The feasibility and usefulness of the proposed procedure was tested through two case studies, each conducted at a manufacturing company in Denmark. Case Company A was the main industrial collaborating partner of the research project, and Case Company B was another flow manufacturing company. The characteristics of the case companies are summarised in Table 4.2.

Table 4.2 - Characteristics of Case Company A and Case Company B

	Case Company A	**Case Company B**
Location	Denmark	Denmark
Industry	Plastics	Chemical
No. of employees	200	2,100
Annual turnover	23 million euros	840 million euros

In Case Study A, all seven steps of the proposed procedure were conducted. However, in Case Study B, the procedure was still ongoing at time of data collection, with only the first five steps finished, so only those five completed steps were considered. Consequently, semi-structured interviews were conducted with key stakeholders in Company B to evaluate the feasibility and usefulness of the approach. The following sections briefly discuss the steps followed in the two case studies. For more details, see Study B in the appendix.

The results of the scoping processes for both case studies are summarised in Table 4.3. For Case Study A, the scope encompassed all product variants that were produced in-house, whereas in Case Study B, only chemical end-products were included. These constitute the main product groups covering approximately 70% of company turnover. In Case Study A, the customers were aggregated into customer chains to conduct the ABC analyses. On the other hand, Case Study B did not involve any aggregation, meaning that each of the customer’s regional locations was evaluated as a separate entity in the ABC analysis. In both cases, the analyses were based on sales order data from a 24-month period. The number of sales order lines, product variants and customers that resulted from the analyses varied significantly between the two cases. In Company A, comprehensive complexity allocation analyses had been conducted prior to the case study, so those costs were included when evaluating the contribution margin of products and customers. However, as no such analyses had been conducted for Company B, no additional costs were included in this case study.

Table 4.3 - Results of scoping process in Case Study A and Case Study B

	Case Study A	Case Study B
Product Scope	All in-house produced product variants	All in-house produced chemical end-products
Customer Scope	Evaluated by aggregation to customer chains	Evaluated by regional location
Data Scope	24-month period 115,000+ sales order lines 1,600 product variants 1,260 customers	24-month period 2,400+ sales order lines 467 product variants 1,004 customers
Cost Scope	Included three complexity cost factors – internal freight, sales order handling and quality control	No complexity cost factors included

As the summarised results of the ABC analyses in Table 4.4 indicate, 902 and 256 C-products were identified in Company A and Company B, respectively. These products were further evaluated for termination in the subsequent steps.

Table 4.4 - Distribution of product variants and customers according to ABC categories

	Case Company A		Case Company B	
	No. of product variants	**No. of customers**	**No. of product variants**	**No. of customers**
A	343 (21%)	65 (5%)	109 (23%)	157 (16%)
B	355 (22%)	168 (13%)	102 (22%)	180 (18%)
C	902 (56%)	1.027 (82%)	256 (55%)	667 (66%)

As Table 4.4 also conveys, only 5% of the customers of Company A were A-customers, meaning that most of Company A’s business came from these relatively few customers. Hence, only protecting the linked revenue of these few customers would be risky. Thus, the decision was made to protect the linked revenue of both A-customers and B-customers. In Company B, the fraction of A-customers was less extreme, so protecting (or not protecting) the linked revenue of B-customers was discussed. Company B took a cautious approach to product variety reduction, a decision was made to also protect the linked revenue of B-customers.

As described in Section 3.3, Company A served two main customer segments with differing needs. The customers in one segment sought to have most of their needs met by a single supplier, while the other segment was mainly cost-driven, meaning those customers were willing to use multiple suppliers to obtain the lowest possible price. Thus, only the first segment was deemed prone to linked revenue, meaning that only the linked revenue of customers belonging to the first segment would be protected in the following analyses. Additionally, in Case A, several strategic C-customers were identified; the linked revenue of these customers was also protected.

The sales order data from the defined 24-month period were analysed to determine whether any of the C-products identified through the ABC analyses had historically been purchased by any of the customers whose linked revenue was designated to be protected. The results for both cases are summarised in Table 4.5.

Table 4.5 - Number of c-products protected from termination due to linked revenue in Case Study A and Case Study B

	Case Study A	**Case Study B**
No. of C-products	902	256
C-products protected from termination due to linked revenue	478 (53%)	203 (79%)
C-products not protected from termination	424 (47%)	53 (21%)

As Table 4.5 shows, the fraction of products protected from pruning due to linked revenue differed significantly between the two cases. This difference is explained by the ways in which customers with linked revenue were identified in each case. Company A served two separate customer segments, of which only one was defined as being prone to linked revenue. This means that products purchased by customers in the segment not labelled as prone to linked revenue were not protected from termination, even if the customers were categorised as A- or B-customers. In Company B, on the other hand, all customers were identified as being prone to linked revenue, meaning that all products purchased by A- and B- customers were protected from termination, regardless of which customer segment had purchased them.

Workshops were conducted at both businesses during which managers identified products to protect from termination despite their poor financial performance at the time of the assessment. The decision-makers at both companies chose to protect products that had only recently been launched and, therefore, had yet to reach their full potential in the market. Case Company A protected an additional 24 products that were being used as components in other, more profitable products. Meanwhile, Case Company B protected one additional product that was created as a direct by-product of a chemical reaction resulting from the manufacture of another product because terminating this product would not lead to any significant reductions in complexity.

Additional workshops were conducted with managers at both case companies to divide the nominated product variants into separate groups according to their turnover values. Then, four termination scenarios were designed, each requiring increasing contribution margin ratios (CMR)/ gross profit ratios (GPR) values for each group of products to be protected from termination. The termination scenarios for Case A and Case B are summarised in Table 4.6 and Table 4.7, respectively. For confidentiality reasons, the turnover and CMR and GPR values have been multiplied by a fixed factor.

Table 4.6 - Termination scenarios for Case Study A

Turnover per year	**Minimum CMR[1] for Scenario 1**	**Minimum CMR for Scenario 2**	**Minimum CMR for Scenario 3**	**Minimum CMR for Scenario 4**
5,000+	Never terminate	Never terminate	Never terminate	Never terminate
5,000 – 2,500	10%	20%	30%	40%
2,499 – 1,000	20%	30%	50%	Always terminate
999 – 500	40%	50%	70%	Always terminate
499 – 0	Always terminate	Always terminate	Always terminate	Always terminate
1) contribution margin ratio				

Table 4.7 - Termination scenarios for Case Study B

Turnover per year	**Minimum GPR[1] for Scenario 1**	**Minimum GPR for Scenario 2**	**Minimum GPR for Scenario 3**	**Minimum GPR for Scenario 4**
100,000+	Never terminate	Never terminate	Never terminate	Never terminate
100,000 – 57,200	Never terminate	10%	10%	20%
57,199 – 40,000	10%	15%	20%	40%
39,999 – 27,100	20%	35%	40%	60%
26,099 – 9,000	40%	50%	60%	Always terminate
8,999 – 0	Always terminate	Always terminate	Always terminate	Always terminate
1) gross profit ratio				

The expected impact of each termination scenario was quantified by calculating the production hours to be released by stopping the manufacture of the products identified and then calculating the expected value to be generated by allocating the released production hours to produce A-products. This resulted in an increase in the annual CM2 or gross profit (GP) of between 60 and 1.84 percentage points. The expected impact of each scenario is summarised in Table 4.8.

Table 4.8 - Impact of termination scenarios in Case Study A and Case Study B

	Case Study A		**Case Study B**	
	No. of products nominated for termination	**Percentage point increase annual CM2[1]**	**No. of products nominated for termination**	**Percentage point increase to annual GP[2]**
Scenario 1	238	0.63	32	0.60
Scenario 2	259	0.81	38	1.06
Scenario 3	331	1.39	39	1.09
Scenario 4	378	1.84	42	1.14
1) complexity adjusted contribution margin; 2) gross profit				

As previously mentioned, the final steps of the procedure had yet to be conducted in Case Study B at the time of data collection. Therefore, the following sections present only the results of Case Study A.

The expected impact of each termination scenario was presented at a steering committee meeting in Case Company A, and the committee decided to continue with Scenario 2, resulting in the nomination of 259 products for termination.

Personalised overviews were created for all customer account managers responsible for customers who had historically purchased any of these 259 products nominated for termination. The managers who wanted to advocate for any of these products to be protected from termination were given two months to provide detailed reasoning to support their position. However, this deadline was extended by an additional two months to ensure that all feedback was collected.

Finally, the feedback from the customer account managers was compiled and presented at a steering committee meeting. The reasons for protecting each product were evaluated, and then a decision was made on whether to follow through with the termination. Seven products were protected from pruning because of the feedback from the customer account managers, resulting in a list of 252 products to be terminated.

Figure 4.3 outlines the process followed to identify products to be terminated in each of the two case studies. The final two step are missing in Case B, as Company B had yet to complete the procedure at the time of data collection, as noted previously.

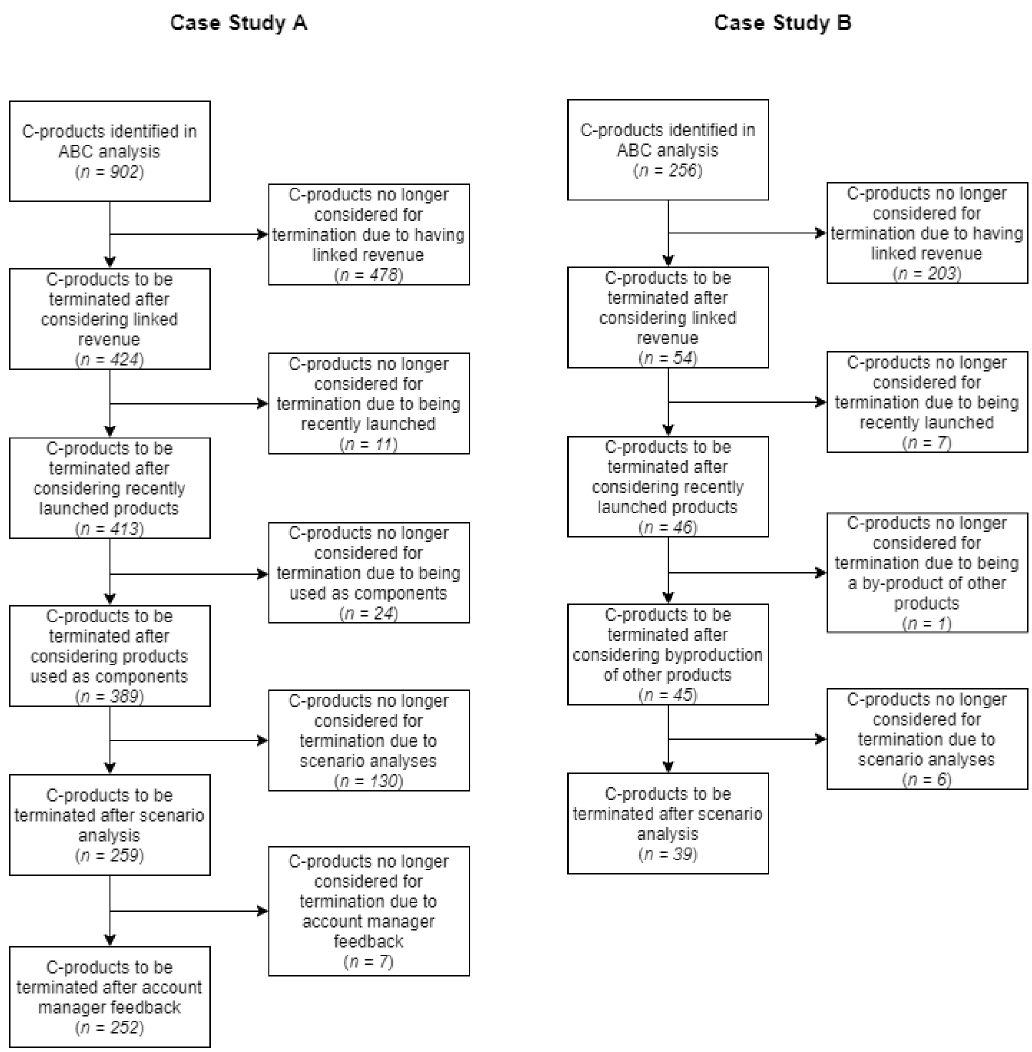


Figure 4.3 - Processes for identifying products to be terminated in the two case studies (Andersen, Andersson, et al., 2023)

4.2.1 Evaluation of usefulness and impact

Interviews were conducted with key stakeholders in the case companies to evaluate the feasibility and usefulness of the procedure. The interviewees noted the procedure was relatively simple and that it could be implemented quickly because only readily available data and limited market knowledge were required. The procedure was also viewed as a useful tool for communicating the rationale for terminating specific product variants while protecting others. The biggest obstacles to implementing the procedure identified were ensuring both data quality and process transparency. Overall, the stakeholders interviewed reported finding the procedure valuable, and stakeholders from Case Company B expressed an interest in conducting the procedure annually going forward because it can be conducted easily and quickly, especially after gaining experience with its implementation.

To determine the value of the proposed procedure, scenarios were created and analysed to examine the outcome if linked revenue had not been considered. This was done by quantifying the impact of following the procedure in each case but without protecting products due to linked revenue (i.e. by skipping Step 3). The results are shown in Figure 4.4 and Figure 4.5 for Case A and Case B, respectively. The leftmost bar in the figures represents the number of C-products identified in each case. This bar is then split into three parts: the bottom segment represents the products nominated for termination as a result of following the procedure; the middle portion represents the products that would have been nominated for termination if linked revenue had not been considered; and the top part represents the products that were not recommended for termination because of the evaluation conducted in Step 5. The middle bar represents the customers who purchased the products from the leftmost bar. In this bar, the top part represents the customers who were defined as having linked revenue, and the bottom segment represents the customers who were defined as not having linked revenue. Finally, the rightmost bar represents the turnover realised by the case company from the customers in the middle bar.

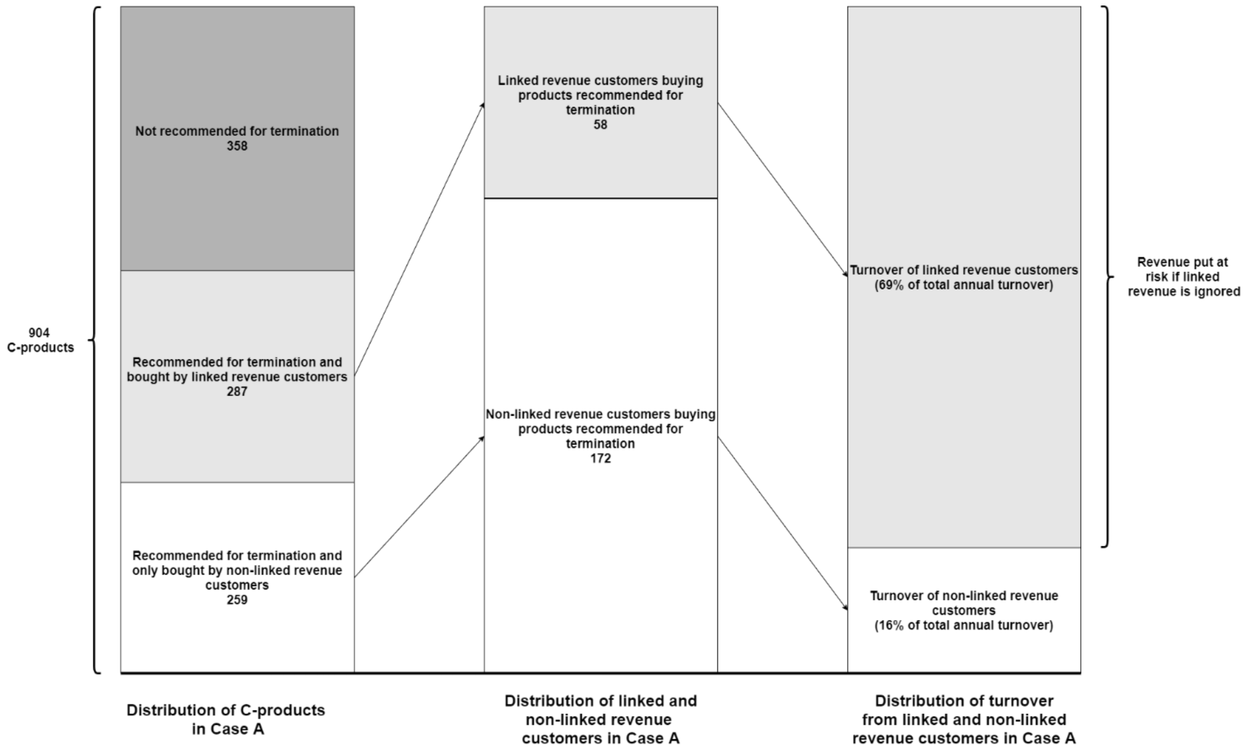


Figure 4.4 - The effect of the proposed procedure in Case Study A (Andersen, Andersson, et al., 2023)

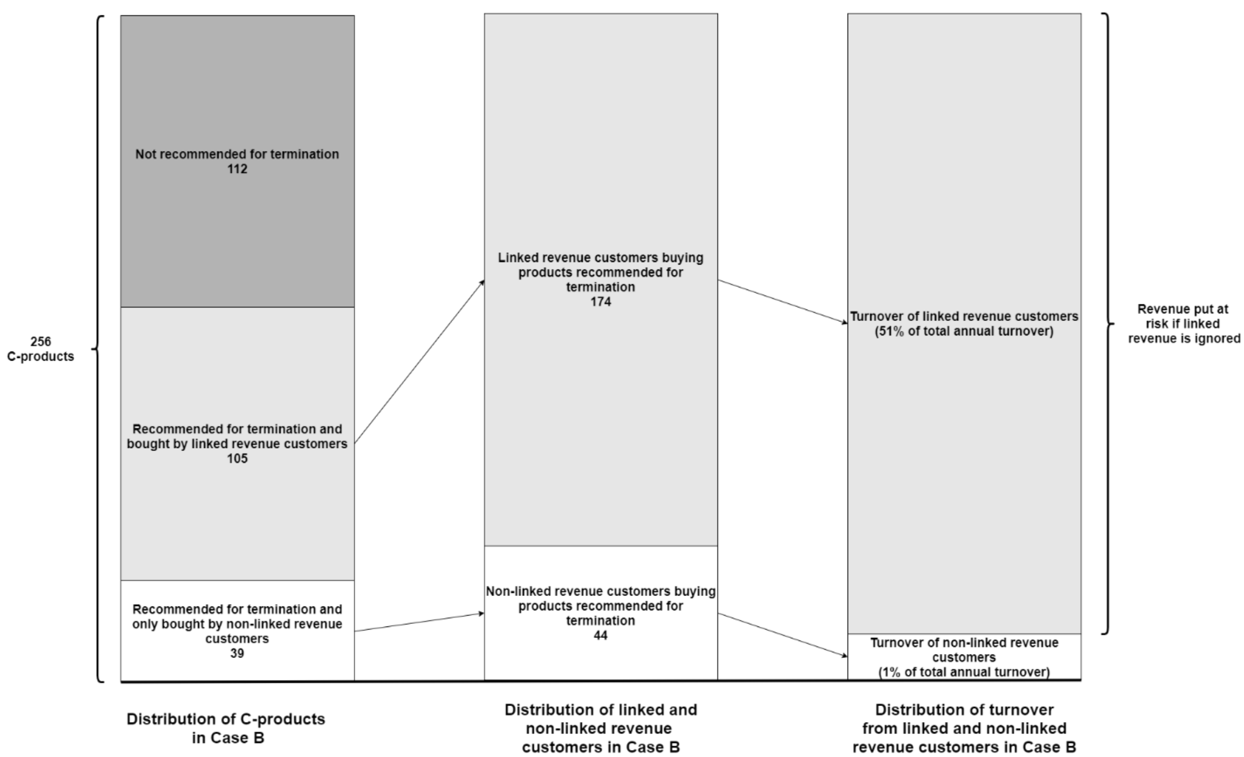


Figure 4.5 - The effect of the proposed procedure in Case Study B (Andersen, Andersson, et al., 2023)

A comparison of Figure 4.3 and Figure 4.4 reveals a notable difference between the distribution of linked and non-linked revenue customers who purchased products recommended for termination in the two cases. More specifically, relatively few customers with linked revenue were identified in Case A compared to Case B. The reason for this, as previously explained, is that case company A served two separate customer segments, only one of which was prone to linked revenue. Consequently, no customers belonging to the other segment were associated with linked revenue, regardless of their sales numbers. Furthermore, as illustrated in the rightmost bar in Figure 4.3 and Figure 4.4, in case A, 69% of the total annual turnover was generated by customers who had purchased one or more of the 287 products that would have been recommended for termination if linked revenue had not been considered. Hence, 69% of the annual company turnover would have been put at risk if linked revenue had not been considered. On the other hand, in Case B, 51% of the total annual turnover was generated by customers with linked revenue who had purchased one or more of the 105 products that would have been terminated if linked revenue had not been considered. Hence, 51% of the annual company turnover would have been put at risk if linked revenue had not been considered. These results clearly illustrate the importance of considering linked revenue in product rationalisation projects.

4.3 Research contribution

Reducing product variety may impact companies' ability to meet the needs of their existing customers, leading to lost revenue if the impact manifests in a customer's decision to do business with other suppliers. In Study B, we termed this phenomenon '*linked revenue*' (Andersen, Andersson, et al., 2023). Existing product variety reduction methods, to a large extent, fail to consider this concept. Thus, Study A and Study B both contribute to explaining how manufacturing companies can reduce product variety while minimising the loss of future business of existing customers by proposing and testing a procedure that identifies products that are unprofitable and that can be terminated without impacting the company's business with its most profitable existing customers, evaluates the potential profitability of these products and reduces internal pushback on the termination of products by involving affected customer account managers in the process.

4.3.1 Definition of linked revenue

Study A and Study B both contribute to the literature by defining the concept of *linked revenue* and demonstrating its relevance to product variety reduction. In the proposed procedure, a binary definition of *linked revenue* is applied, meaning that if a product has ever been purchased by a customer whose linked revenue is to be protected, then the product is protected from termination. In reality, though, products have varying degrees of *linked revenue*, as some products are more important to specific customers than others, and termination of these less important products may not impact the future business of these customers. However, determining the degree of *linked revenue* for individual products to individual customers requires extensive market, product and customer knowledge. As such, the proposed procedure is intended to serve as a simple step-by-step technique for manufacturing companies to follow to reduce product variety while protecting linked revenue. Moreover, only data that are readily available directly from the ERP systems of companies and only limited market, product and customer knowledge are required to implement the procedure. Thus, the procedure can be used to identify *the lowest hanging fruits* and assist companies in gaining experience in conducting product variety reduction projects. This experience may enable additional, and more complex, product variety reduction projects in the future, such as one based on a more elastic definition of *linked revenue*. Nevertheless, the binary definition of *linked revenue* simplifies the proposed procedure, which was a strength and a value of the procedure highlighted by key stakeholders from the case companies in the evaluation interviews.

4.3.2 Reducing internal pushback

Sales departments represent a common source of internal pushback on product variety rationalisation projects. The performance of sales personnel is typically measured by the amount of turnover they generate. They are, therefore, not incentivised to reduce the available product variety that is offered to customers, even if part of this variety is ultimately unprofitable for the company because more variety translates to more options to sell to customers, which may translate into more sales. The plastic company company encountered this issue on several occasions. Analyses had been conducted to identify unprofitable products that were nominated for terminations, but these efforts were ultimately stopped when the approval of the sales department was sought. The proposed procedure is designed to reduce this internal pushback on the termination of products by directly including the affected customer account managers in the process. Personalised overviews are created for each affected customer account manager that help them to easily identify specific products that they believe should be protected from termination and to provide detailed reasoning to support their position. This is done for two reasons. Firstly, customer account managers may have valuable insights into the reasons that certain products should be protected from termination, such as being engaged in ongoing negotiations of profitable future contracts. Secondly, requesting that managers provide their feedback on the list of products nominated for pruning reduces the internal pushback. In the post-case evaluation interviews in Case A, the account managers expressed appreciation for the way their input was collected and considered as a key element of the procedure.

4.3.3 Evaluation of potential profitability of individual products

As previously mentioned, when conducting the ABC analyses, products and customers that received different ABC ratings for turnover than for contribution margin were ultimately assigned the lower of the two for their final rating. Consequently, a product could possibly receive a C-rating for its contribution margin and an A-rating for its turnover and ultimately be categorised as a C-product. This type of C-product, however, represents a much larger potential in the market compared to a C-product with a low turnover value because the type of C-product described in the previous sentence is currently being sold to customers on a large scale. If the sales price was increased and/or the production costs were decreased, these types of C-products could become profitable. Therefore, they should not be blindly terminated.

Consequently, a systematic and simple way to evaluate the potential profitability of individual product variants was needed. Therefore, we decided to evaluate products for termination based on their turnover and CMR based on the premise that the higher the turnover of a product, the larger its potential for becoming profitable through sales price increases or cost reductions, thereby making a smaller CMR acceptable. Conversely, even if a product has a high CMR, if its turnover is low, it will still not cover its expenses. Therefore, products with low turnover rates need a higher CMR to be protected from termination. The outcome of this process is a list of currently unprofitable products with high potential profitability. Therefore, initiatives can be launched to either re-negotiate sales prices or to reduce production costs to increase the profitability of these products.

4.3.4 Identification of relevant customers

An important step when seeking to minimise the loss of customers due to product variety reduction is to identify which customers are relevant to consider. Companies often serve several customer segments with different needs, and not all customer segments are equally prone to linked revenue. Some segments may value having their needs met by a single supplier, while other segments may be primarily cost-driven and, thus, willing to have multiple suppliers of similar products to obtain the lowest possible price. Additionally, companies may serve customers that currently do not generate profits but are expected to become profitable customers in the future. The linked revenue of any such strategic customers should be protected.

Finally, a more general decision should be made regarding which customers are important enough to merit having their linked revenue protected. The linked revenue of A-customers should always be protected. However, as the distribution of A-, B- and C-customers varies from company to company, whether to also protect the business of B-customers is case-dependant. In companies with few, very large A-customers, protecting only the linked revenue of these customers would be risky. Which customers' linked revenue to protect also depends on the willingness of company management to put the business of B-customers at risk.

4.3.5 Additional reasons for protecting unprofitable products from termination

When analysing which unprofitable products to terminate, various reasons not to terminate products should be considered (Wilson & Perumal, 2009). Therefore, the proposed procedure contains a step specifically intended to identify relevant reasons for protecting product variants from termination and to identify the specific products to be protected for these reasons. Following are potential reasons to protect variants from termination:

- Products that have only recently been launched that need time to reach their sales potential in the market (while the time required to reach that potential varies across different types of products and, therefore, should be evaluated by the company).
- Products that the company is obligated by contract to offer to certain customers.
- Products without which the product range within a certain product family may appear incomplete.
- Products that are both being sold as finished products and being used as components in other, more profitable products.

- Products within certain product ranges that are currently unprofitable because they are produced using new and expensive production technologies but may become profitable in the future if the technology improves and becomes cost efficient.
- By-products derived from chemical side reactions of manufacturing processes that are not considered waste and the products derived from the primary/main production output, the termination of which would not lead to significant process simplifications or complexity reductions.

5 How can manufacturing companies manage and reduce product-related service variety while protecting the future business of existing customers?

Manufacturing companies are moving from primarily selling physical products to also offering a wide selection of services to support those products (Guillon et al., 2021). A significant component of the value proposition and complexity in modern manufacturing companies is related to these product-related services (Vandermerwe & Rada, 1988). Examples of product-related services include maintenance, financing schemes, takeback agreements, product transportation, installation and providing repairs and spare parts (Gaiardelli et al., 2014; Guillon et al., 2021; Lenfle & Midler, 2009; Tukker, 2004). Offering product-related services can be highly profitable; however, many companies struggle to determine which services to offer and to define these services (Cusumano et al., 2010; Raja et al., 2018). Furthermore, the adoption of servitisation strategies requires companies to organise their resources in new ways to provide these services efficiently and effectively (Hakanen et al., 2017).

The challenges faced in ETO product development and sales processes are similar to those related the creation of customer-specific product-related services. Several approaches for developing configurators are described in the literature as well (Forza & Salvador, 2006; Haug et al., 2012, 2019; Hvam et al., 2006, 2008a; Mueller et al., 2022); however, most of these only include physical products, and none address the unique challenges related to the management of product-related services. These challenges are mainly related to the scoping, analysis and modelling parts of the configurator development process and include the challenge of systemically mapping existing product-related services and evaluating which to include in the scope of the configurator. The cost and availability of individual product-related service variants are mainly governed by the characteristics of the specific physical products being sold and the customers to whom they are sold (Guillon et al., 2021). Part of effectively managing product-related services, therefore, is the formulation of relevant constraints to prevent impossible and unwanted combinations of products, customers and product-related services. Additionally, as the cost of individual service variants can vary significantly depending on the characteristics of the selected customers and the physical products, being able to accurately calculate the cost of providing product-related services to specific combinations of products and customers is vital. In addition, over- or underestimating the cost of providing product-related services introduces the risk of committing to unprofitable contracts or demanding non-competitive prices from the market, thereby potentially losing business (Benedettini et al., 2015; Raja et al., 2018). Finally, during the modelling phase of a configurator development project, models should be adapted to appropriately express the structure and characteristics of product-related services.

To address the gap in the literature created by the lack of appropriate methods for developing configurators for product-related services, Study C proposes an approach to developing and implementing configurators for product-related services and tests the usefulness of the proposed approach in a case study (see appendix for full text).

The most fundamental product-related service provided by manufacturing companies is *product delivery*. Research has shown that significant benefits can be obtained by improving delivery performance (Mewborn et al., 2014; Nagar & Rajan, 2001; Peng & Lu, 2017; Rao et al., 2014). A common measure for assessing the success of a product delivery service is the on-time delivery (OTD) rate, defined as the percentage of orders delivered on time. When quantifying OTD, the time of delivery is compared with a *comparison date* to evaluate the timeliness of orders (Forslund & Jonsson, 2007). The measure of the timeliness of orders according to the delivery date confirmed by the supplier is referred to as the supplier-confirmed on-time delivery (SC-OTD) rate, and it provides an assessment of how well a supplier can comply with what it promises to its customers. On the other hand, the measure of the timeliness of orders according to the delivery date requested by customers is referred to as the customer-perceived on-time delivery (CP-OTD) rate, and it provides a useful measure of how well a supplier is able to comply with the needs of its customers (Forslund & Jonsson, 2010; Knoblich et al., 2015). However, the use of CP-OTD has received limited attention in literature.

When quantifying OTD, the *time unit* or *delivery time window* defines the period during which an order must be delivered for the delivery to be considered on time (Forslund & Jonsson, 2007). As customers are growing increasingly heterogenous and demanding (Stäblein et al., 2011), the need for the metrics used to quantify OTD to reflect the needs of individual customers becomes more important. For example, for some customers, an order line that is delivered one day prior to the promised date is considered on time, while others may not tolerate early deliveries. Consequently, to accurately quantify OTD, different delivery windows should be defined to reflect the heterogenous delivery requirements of different customers. However, the impact of using several delivery time windows has also received only limited attention in literature.

To contribute to this gap in literature, a systematic literature review was conducted for Study D to synthesise how OTD performance is defined in the academic literature (regarding the use of different comparison dates) and with a subsequent focus on how CP-OTD has been used as a performance measure. This was followed by a case study at the site of the industrial collaboration partner company to explore how enhancing delivery performance measurement systems with customers' requested delivery date, appropriate delivery time windows for heterogenous customers and various market contingencies can enable companies to better manage product delivery services and to identify potential areas of improvement.

5.1 An approach for developing and implementing configurators for product-related services

Existing approaches for developing and implementing configurators do not address the distinct obstacles related to the management of product-related services. To address this gap, as part of Study C, an approach to developing and implementing configurators for product-related services was proposed. The usefulness of the proposed approach was tested through a case study at plastic company.

5.1.1 The proposed approach for product configurators of product-related services

Although no approaches for the development and implementation of configurators for product-related services were found in the literature, some articles discuss relevant insights that can be exploited when developing such an approach. One such insight is the concept of service modularisation. Just as physical products can be broken down into sets of components or modules (Aldanondo & Vareilles, 2008; Schierholt, 2001; Zhang et al., 2013), services can similarly be broken down into modules (Böttcher & Klingner, 2011), despite being intangible (Guillon et al., 2021). To develop service configurators, they must be based on a modular service architecture (Hellström et al., 2016) that should be envisioned using visualisation techniques, such as process graphs (Cao et al., 2006; Schierholt, 2001). Additionally, when modelling service offers, the context in which an offer is taking place must be considered (Guillon et al., 2021), including the market state, customer profile, the future state of the company and customer requirements. These insights were considered in the development of the proposed approach.

The proposed approach for developing and implementing configurators for product-related services was based on existing approaches to developing configurators (Haug, Hvam, & Mortensen, 2012; Hvam et al., 2019; Hvam, Mortensen, & Riis, 2008; Forza & Salvador, 2006; Mueller et al., 2022), with modifications to make the strategy suitable for product-related services. The proposed approach is achieved through five overall steps, each with related sub-steps (see Figure 5.1). The most significant modifications concern the scoping, analysis and conceptual modelling of the configurator. The remaining steps are not significantly modified in comparison to the existing approaches.

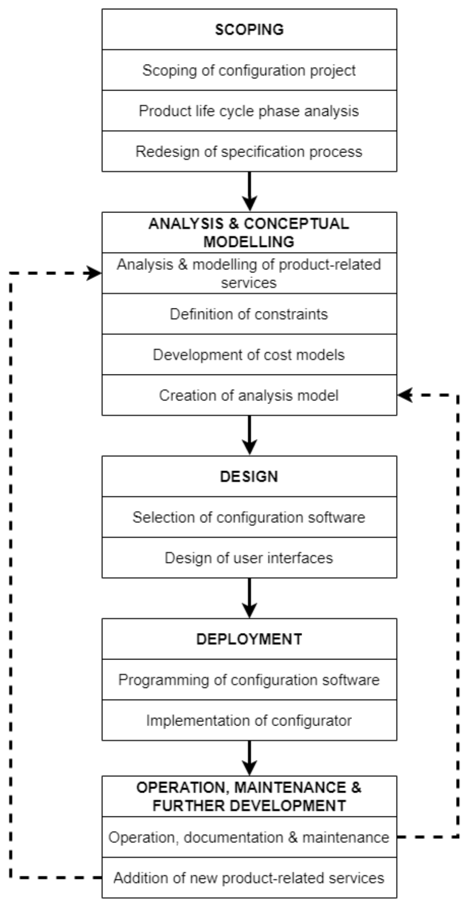


Figure 5.1 – The proposed approach for the development and implementation of product-related service configurators (Andersen, Hvam, & Haug, 2023)

Step 1: Scoping

First, the overall requirements of the configurator to be developed are defined based on an analysis of the needs of the company. Manufacturing companies typically maintain a comprehensive overview of the physical products that exist in their portfolio; in addition, an overview of these products can be extracted from ERP systems. However, this may not be the case for the product-related services that manufacturing companies offer. Therefore, the next step is to conduct analyses to identify all existing product-related services offered by the company. Product-related services can be divided into groups according to the point in the life cycle of the product at which they occur. Therefore, domain experts linked to each existing product life cycle are gathered at workshops, during which all existing product-related services are listed. This systematic process is designed to ensure that no existing product-related services are overlooked and to structure the output of the analysis.

Armed with a comprehensive list of the existing product-related services offered by the company, decisions should now be made regarding which service to include in the scope of the configurator. These decisions should be made based on three criteria: (1) cost, (2) data quality/availability and (3) customer value. Firstly, product-related services that are costly to provide to customers have a larger impact on the total cost of the final offering. Therefore, more costly product-related services should be prioritised to be in the scope of the configurator. The second group of product-related services that should be prioritised to be in the scope of the configurator are those for which high-quality data are readily available related to existing service variants and to the costs related to providing the service. If the data available are not of a high quality, then the data must be created, which can involve a lengthy and expensive process as it may require extensive process analyses and time studies. Thirdly, even if a product-related service is not costly to deliver, if it provides significant value for customers, it represents an opportunity for the company to increase sales prices. Therefore, product-related services that customers value highly should be prioritised to be in the scope of the configurator.

Next, the current product-related service specification process should be mapped and visualised using flowcharts or graph models. Based on these insights, the specification process should be redesigned to handle the requirements of the new configurator while meeting the requirements and goals of the company.

Step 2: Analysis and conceptual modelling

Workshops with relevant domain experts are conducted to list all existing service variants for each product-related service. Decisions should then be made regarding which service variants to include in the scope of the configurator, while the remaining product-related service variety should be terminated. To prepare the scope of product-related services to be included in the configurator, they should be modelled according to a modular architecture. This includes the definition of the modules to eventually comprise the product-related services, as well as the attributes required to describe these modules.

When configuring product-related services, the solution space is mainly governed by the selection of product variants and customers. These constraints have a twofold purpose. First, constraints prevent users from creating impossible configurations, such as preventing the packing of items that exceed certain physical dimensions into boxes that are too small to contain them. Second, constraints can strategically prevent users from offering services that the company has decided not to provide to specific groups of customers, such as preventing same-day express shipping to customers located in a certain region. Each product-related service variant is analysed, and constraints are defined at workshops with relevant domain experts. In this context, the people who define the constraints of a configurator are often different from those who program the configuration software. Therefore, constraints should be expressed in a way that is simple to understand for both groups of people. One option is to express constraints as lines of pseudo code or in the form of constraint tables (Hvam et al., 2008b).

In accordance with the selected product, customer and product-related services, the configurator should calculate the specific cost of each product-related service separately. The total cost of the offering is then calculated by summing the costs of each service and product. Therefore, a customised cost model should be designed for each product-related service within the scope of the configurator. The first step is to decide on the desired format for the output of each cost model. For example, the output can be expressed as the product-related service cost per unit of products sold or as the total product-related service cost across the total quantity of products in the offering. The output should be expressed using the same format for each cost model to enable the configurator to easily calculate the total cost of the offering by simply summing the costs of each individual service in the configured offer. The cost of providing product-related services for individual offers is directly connected to the characteristics of the selected products and customers. For example, the cost of shipping a pallet of products depends on the geographical location of the customer. Furthermore, the shipping and order handling costs incurred by shipping 10 products in a single order are lower than the cost of shipping one product in 10 separate orders. The cost is also directly related to the specific service variants selected. The nature of what drives the cost of a product-related service differs depending on the type of service. Some services are directly driven by the number of products sold (e.g. the cost of installation is the same for each product sold), while other services represent a fixed cost per order (e.g. offering customers order tracking incurs a fixed cost per order). Therefore, the cost per product sold for this service decreases as the quantity of products in each order increases. A third type of situation involves services that represent a fixed cost, regardless of the number of products sold or number of orders placed. One example is the cost of creating a documentation report that details the characteristics of a product for which the service cost per product sold decreases when the total number of products sold increases because the cost is split evenly across each unit sold. Figure 5.2 illustrates the nature of product-related service costs with different cost drivers.

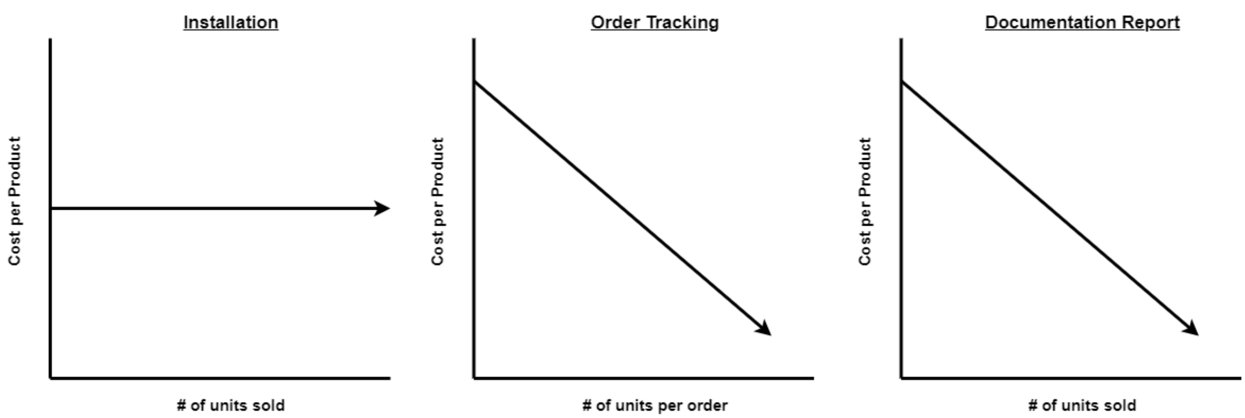


Figure 5.2 - Product-related services with different cost drivers (Andersen, Hvam, & Haug, 2023)

All customers, product variants and product-related service variants are to be gathered into an analysis model to illustrate the modular structure of each product-related service. This model also should contain all the defined constraints and the cost models developed. The purpose of the analysis model is to include all the information required to understand the structure and logic of the configurator and to be used as the basis for programming the configurator in the selected software shell. As configurator development requires input from stakeholders and domain experts from different departments within a company, each with different levels of modelling experience, the modelling technique used for the analysis model should be relatively simple to understand. Therefore, the product variant master (PVM) is recommended for use as the modelling technique because it is easy to learn and read (Haug et al., 2012).

A PVM typically contains a *Customer View* that describes choices related to the customer and a *Part View* that describes the specific physical components to be used in the final product. This traditional PVM structure is extended with a *Product-Related Service View*, in which each product life cycle phase is represented as a separate module. These modules contain product-related services that are connected to the product life cycle phase. Figure 5.3 shows an example of a simple analysis model in the shape of a PVM. For an in-depth explanation of this figure, see the full text in the appendix.

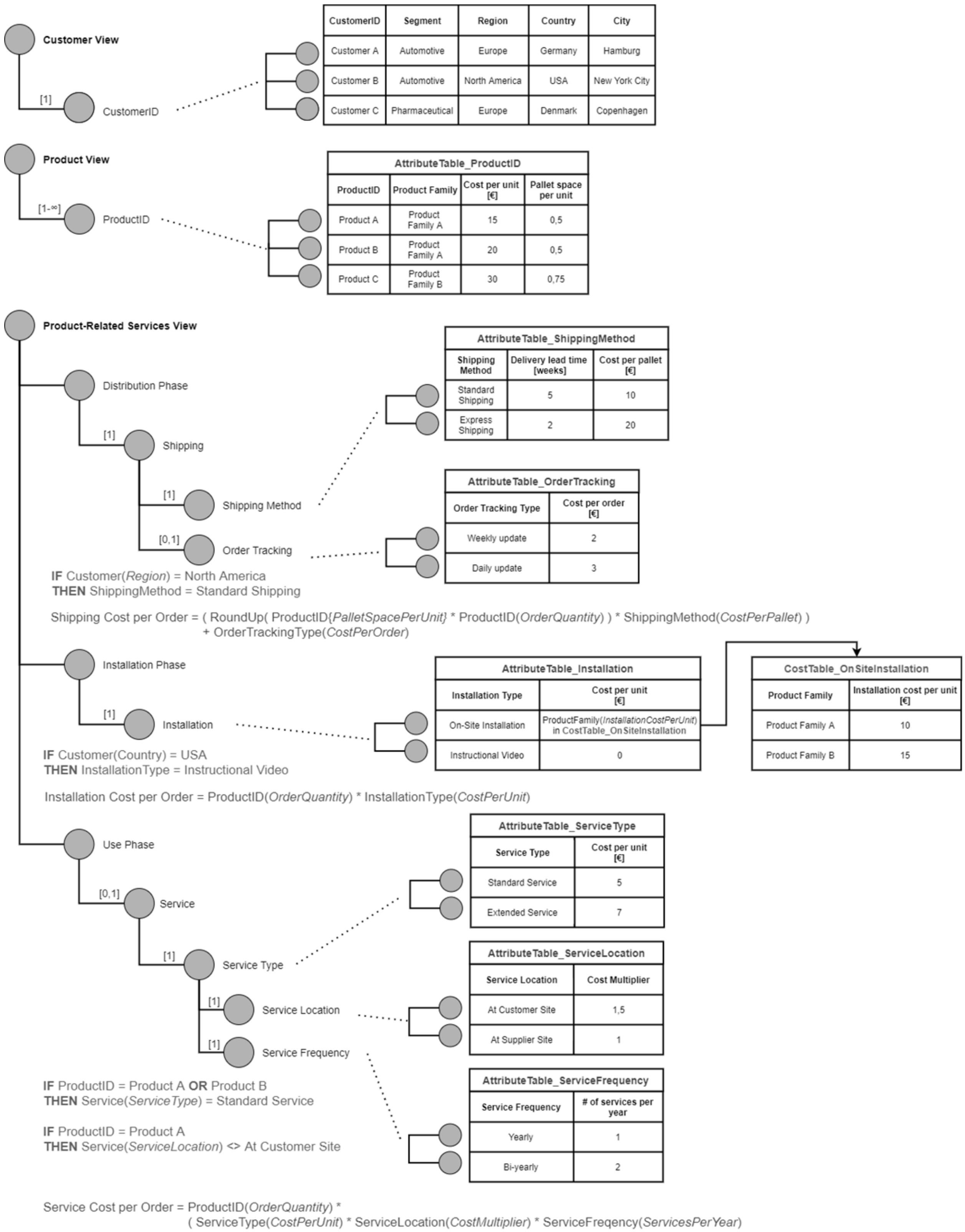


Figure 5.3 - Example of a simplified product variant master with product-related services, constraints and cost models
(Andersen, Hvam, & Haug, 2023)

Step 3: Design

A decision should be made regarding whether to use an existing configuration software shell or to develop custom configuration software from scratch. Some commonly used configuration software shells include Configit Product Modeler, Baan Product Configurator, Oracle Configurator, Tacton Configurator and Cincom Knowledge Builder (Haug et al., 2012).

Additionally, the design of the user interfaces to be used in the configurator should be defined. These decisions should be determined by the type of user and the purpose of the system. Therefore, workshops are conducted with end users of the system to determine the user interfaces to be used in the final configurator. The chosen design must ensure that users are provided with the relevant information at the appropriate time and that they are guided throughout the process of creating a configuration. This includes both the order in which the input is entered and the visual design of each interface. Additionally, automatic prompts can be developed to provide users with relevant information based on their input. For example, the system might notify the users if an alternative and similar service variant exists that would be less expensive to offer based on their input.

Step 4: Deployment

During this step, the configuration software is programmed based on the scope, attributes, constraints and calculations defined in the previous steps. The system is then tested and adjusted based on the results of the tests. End users are trained in how to use the system, and relevant departments and internal systems are prepared to produce and deliver the product-related service variants defined in the configurator.

Step 5: Operation, maintenance and further development

The analysis model and configurator software should be updated to reflect any changes that occur regarding the service variants offered by the company or the cost structure of services. The modular nature of the analysis model facilitates easier extensions to the configurator. When a new product-related service is to be added, the relevant modules, attributes, constraints and cost models are developed and added as an additional module in the analysis model. As the cost of a service is calculated separately for each view, this can easily be added to the system.

5.1.2 Testing the usefulness of the proposed approach

The usefulness of the proposed approach was tested through a case study at the plastic company. Prior to the case study, the process of specifying product-related services was conducted manually. Sales personnel specified the products to be quoted, based on which suggested sales prices were calculated. After this, the product-related services were manually selected from a list, and a fixed service cost was added to the quote. The selection of product-related services was not constrained by the customers or products selected, which led to the risk of creating quotes containing impossible combinations of customers, products and product-related services. Furthermore, the cost calculations of product-related services were not connected to the characteristics of the individual quotes, meaning that the cost of product-related services was expected to be covered by the contribution margin of each quote.

Step 1: Scoping

The configurator was to be used by the sales personnel to develop customised offerings for customers, including both physical products and several product-related services. Based on the products, customers and services selected, the expected costs of delivering the proposed offerings should be calculated, and the suggested sales prices should be calculated based on the desired target CMR. Alternatively, the user should be able to manually input a sales price for each offering, and the system will then calculate the resulting CMR.

Workshops were conducted with company domain experts to create a comprehensive list of all existing product-related services being offered. A total of 29 product-related services were identified spread out among seven product life cycle phases. (Due to confidentiality considerations, the full list of product-related services is not presented.) Each identified product-related service was rated on a scale of 1–5 according to cost, data quality/availability and customer value. The scores were summed, and the four highest ranked product-related services were selected to be included in the scope of the configurator.

The product-related services selected were box repacking and customised labelling, both linked to the packing product life cycle phase; shipping method, linked to the distribution product life cycle phase; and documentation report, linked to the product use life cycle phase. Table 5.1 contains additional information on the four product-related services selected to be included in the scope of the configurator.

Table 5.1 - Product-related services included in the scope of the configurator

Product Life Cycle Phase	Product-Related Service	Description
Packing Phase	Box Repacking	The company offers customers their choice of a selection of boxes in various dimensions and the option to select the quantity of products packed in each box.
	Customised Label	The company offers to label each box of products with various types of customised labels.
Distribution Phase	Shipping Method	The company offers to ship orders as individual, free-standing boxes, as boxes stacked on wooden pallets or as packages to be picked up by customers.
Use Phase	Documentation Report	The company offers a documentation report containing data on product characteristics, test lab results, production records and similar information.

The current specification process was analysed to better understand the changes required to enable the use of the configurator. Based on the insights gained, the specification process was redesigned to fit the purpose and scope of the configurator. The current and redesigned specification processes are illustrated in Figure 5.4, and in-depth descriptions of both processes can be found in the full text in the appendix.

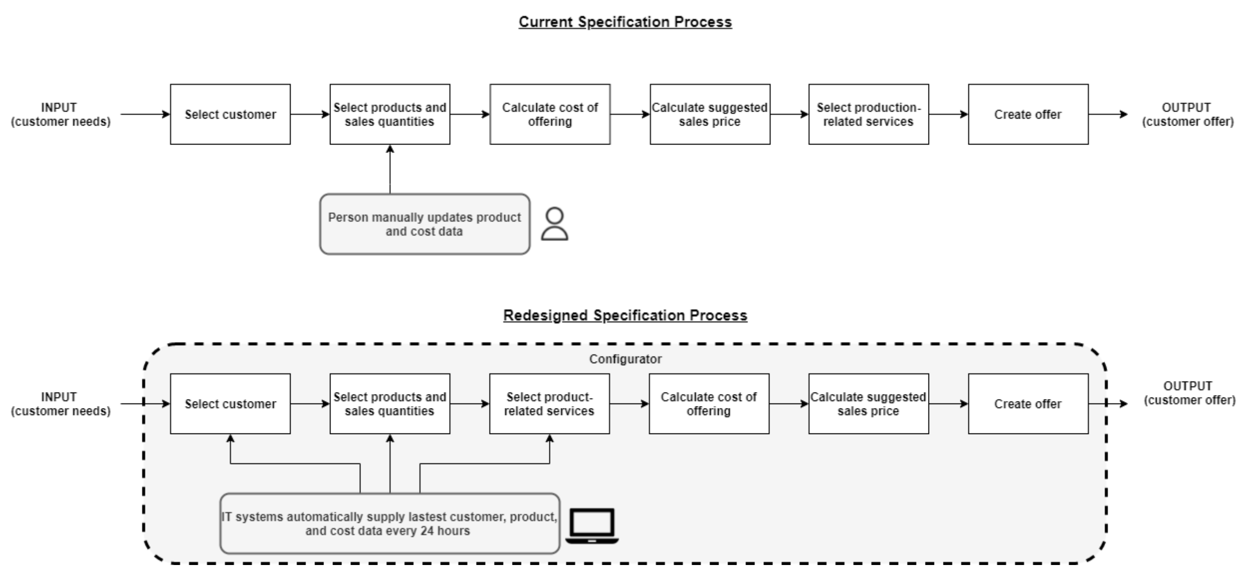


Figure 5.4 - Diagrams of the current and redesigned specification processes (Andersen, Hvam, & Haug, 2023)

Step 2: Analysis and conceptual modelling

Workshops were conducted with relevant domain experts for each of the four product-related services. At these workshops, all existing service variants were mapped, documented and modularised. Furthermore, discussions were held to define which service variants to include in the configurator, after which the modules and attributes required to describe the characteristics of these variants were identified and recorded.

The box repacking and customised labelling services are the simplest of the services in scope. However, prior to the case study, a large number of variants existed for these services. At the workshops, a decision was made to significantly reduce the number of service variants to be included in the scope of the configurator.

The process of listing all existing service variants for the documentation report service was more complicated. The existing process for creating documentation reports was poorly structured and not formalised. Each documentation report was treated as a unique project to a large extent. Therefore, a project was launched to analyse the process and to structure it into well-defined and standardised modules. Ultimately, the service was split into three separate modules, each containing three variants. Consequently, the complexity of creating documentation reports was significantly reduced, as the standardised modules could be reused to a certain degree when new reports were to be created.

Finally, for the shipping service, three shipping methods existed: shipping items in individual free-standing boxes, shipping item in boxes stacked on pallets or dispatching items in packages to be picked up by customers at the site of the company. Generally, if the order volume is high, then shipping items in boxes stacked on pallets will be most cost-efficient. However, as the order volume decreases, eventually shipping the items in individual free-standing boxes becomes more cost-efficient because filling an entire pallet is no longer possible. The specific volume of products representing the point at which it will become more cost-efficient to ship in individual free-standing boxes depends both on the dimensions of the selected product and on the customer's geographical location. As the configurator can calculate this, a fourth *flexible* shipping method was added that would automatically select the most cost-efficient shipping method depending on the combination of the selected products and customer. Two additional modules were also defined. The first specified whether the customer would be responsible for booking the logistics service, and the second indicated whether customers should pay an additional fee for the pallets shipped to them.

Next, workshops were conducted to define how specific customer, product and service attributes should limit the solution space of the product-related services in the configurator, thus ensuring that impossible or unwanted combinations of customers, products and services would not occur. Various types of constraints were formulated and expressed as pseudo code to ensure easy programming of the configurator. In-depth descriptions of these constraints can be found in the full text in the appendix.

After the workshops were held and the constraints formulated, customised cost models were developed to calculate the cost of providing each service, depending on the choice of customer, product and service variant. A project was initiated to collect and record the data required to calculate the cost for each service variant, which included details on the costs of shipping boxes and pallets to the location of each customer, repacking products into different types of boxes and creating documentation reports of various types. These data were defined as attributes of the service variants and then imported into and used in the cost models for the configurator. For each product-related service, workshops were conducted with relevant domain experts. At these workshops, the cost structures of the product-related services were analysed, and the relevant cost drivers were identified. Cost models were then designed to calculate the cost of each product-related service according to the identified cost drivers and the attributes of the service variants. For three of the product-related services, several iterations were required before sufficiently accurate cost models were designed. Furthermore, during these iterations, the need for additional cost data was identified, and projects were launched to collect and record these data. In-depth explanations of each of the developed cost models can be found in the full text in the appendix.

Finally, the results of the previous steps were gathered into an analysis model using PVM as the modelling technique. Data on more than 6,700 customers and 2,800 product variants, along with the nine modules comprising the architectures of the four product-related services, were included in the analysis model. All possible customer, product and service variants were described by attributes in the related attributes tables. Additionally, the costs of handling and shipping boxes and pallets to all existing locations were presented in cost tables. The analysis model also contained the constraints and cost models that were previously developed. The finished analysis model is shown in Figure 5.5. (Due to confidentiality concerns, the details are not shown.) A total of 14,254 unique configurations of product-related services were identified based on the defined modules, service variants and constraints. These can be combined with the selection of more than 6,700 customers and 2,800 product variants when orders are configured.

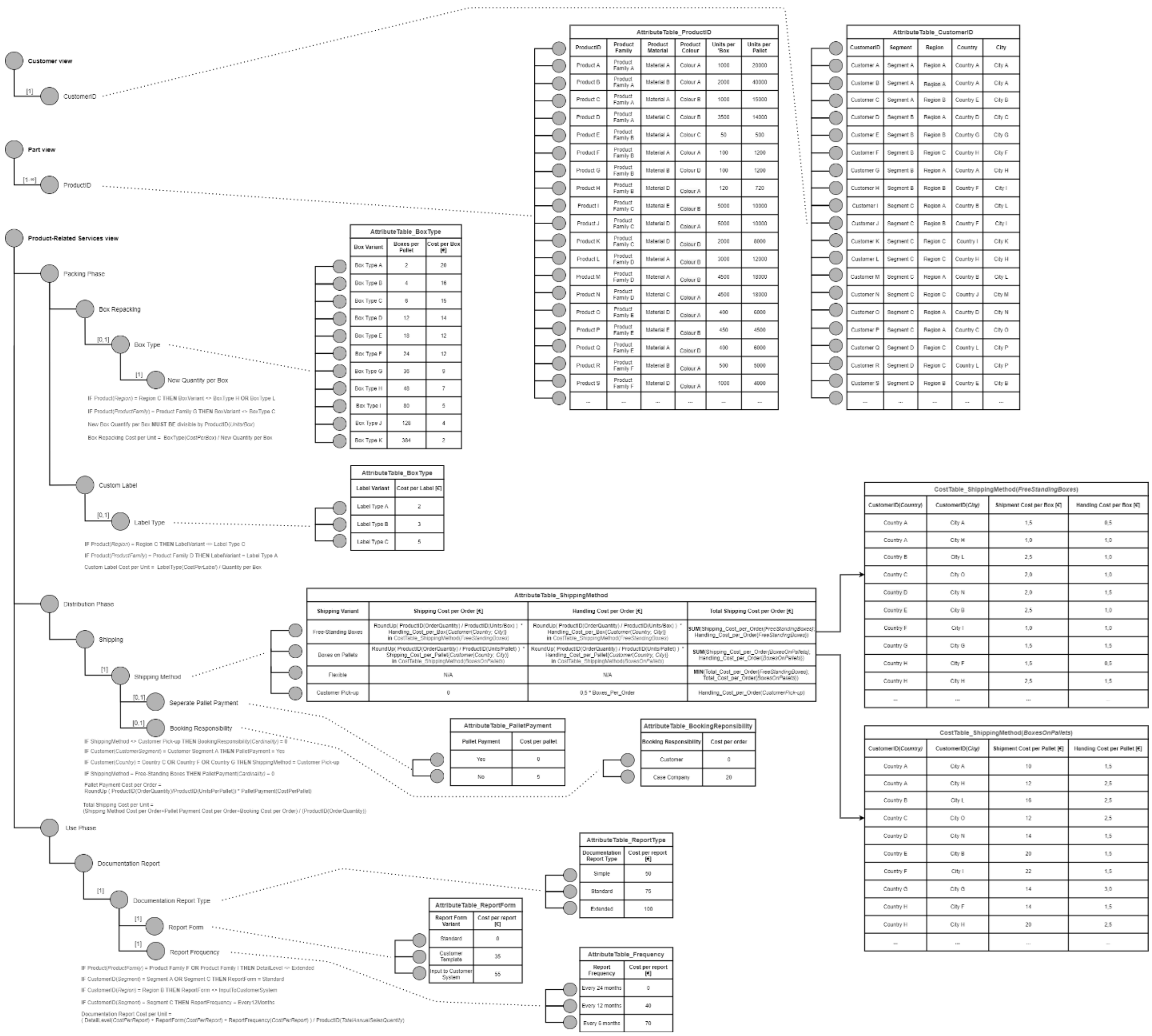


Figure 5.5 - Analysis model created during the case study (Andersen, Hvam, & Haug, 2023)

Step 3: Design

During the case study, the company being observed was unsure of the potential value of a configurator; therefore, a decision was made not to invest in a specialised configuration software shell. Instead, Microsoft Excel was selected as the software to use to create the configurator.

However, after having implemented this initial configurator, the company decided to purchase dedicated configuration software and launched a project to transfer the configurator into this software shell.

Various mock-ups of potential designs for user interfaces were made, along with flowcharts illustrating different methods of navigating between interfaces. Workshops were conducted to decide on the final design of the user interfaces to be used in the configurator. The final design of the navigation in the configurator and the recommended navigation flow are illustrated in Figure 5.6.

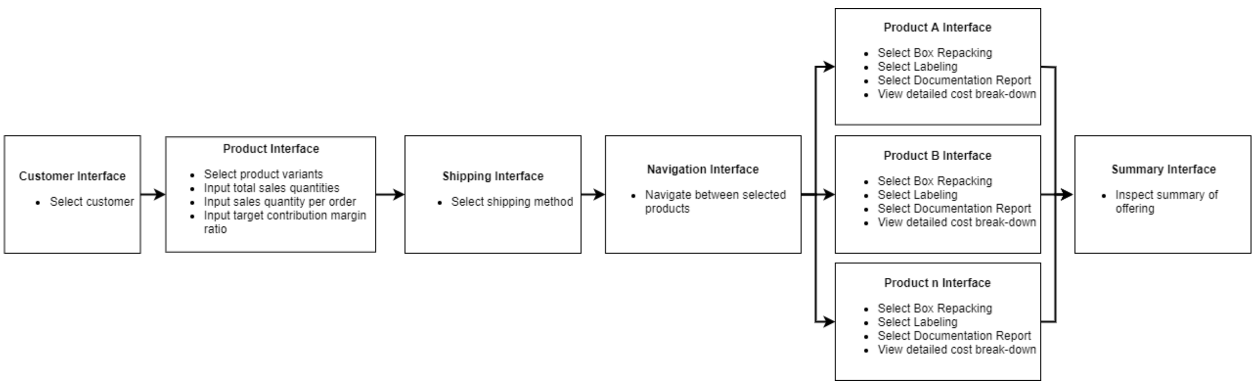


Figure 5.6 - User interfaces of the configurator (Andersen, Hvam, & Haug, 2023)

Additionally, several automatic prompts were incorporated into the configurator. For example, the configurator calculates the extent to which a share of each pallet shipped will be empty. If a significant share of each pallet is empty and the freight cost is high, the system will inform the user that significant savings can be made by increasing the product unit quantity per order or by offering an alternative shipping method. Additionally, the system calculates the cost of all available shipping methods and informs the user if more cost-efficient options exist. This information can be presented to customers who might be willing to change their shipping method or order quantity to receive a lower sales price.

Furthermore, as the cost of the *documentation report* service is not related to the number of product units sold, the cost of this service becomes very high for products with low total sales quantities. If the cost of the *documentation report* service takes up a significant fraction of the total cost of the offering, then the user is notified. This can then be communicated to customers, who will be informed of the option to select a less costly documentation report variant or to increase the total sales quantity to reduce the relative cost of the service.

Step 4: Deployment

Based on the information gathered into the analysis model and the designed user interfaces, the configurator was programmed in the selected configuration software, Microsoft Excel. Beta versions of the system were presented to selected end users, who identified bugs and provided feedback and improvement ideas. Based on their feedback, minor changes were made to the system. The final interfaces of the finished configurator are illustrated in Figure 5.7.

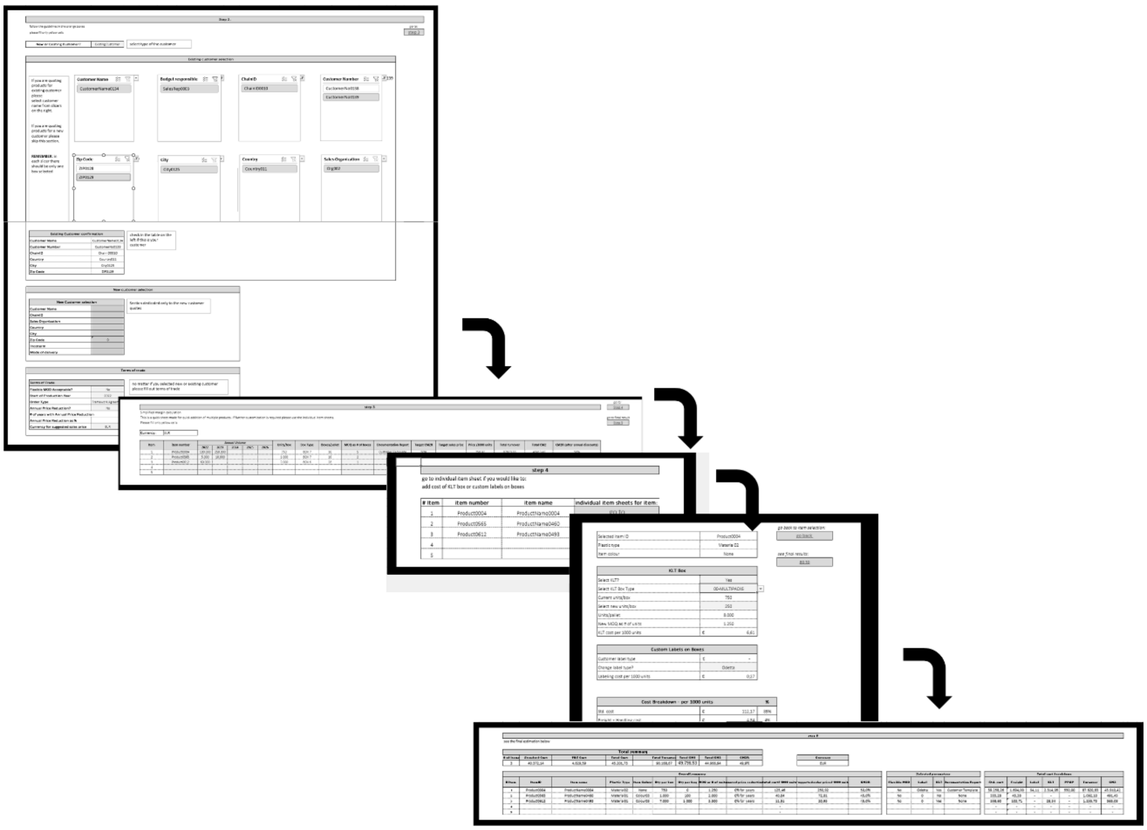


Figure 5.7 - Final user interfaces of the configurator (Andersen, Hvam, & Haug, 2023)

The broader group of users was trained in how to use the system, after which it was officially launched. The end users were encouraged to issue support tickets if any issues were encountered. Based on these support tickets, several minor issues were addressed.

Step 5: Operation, maintenance and further development

Previously, the list of available products to choose from when creating quotes was manually updated when new products were launched or when changes to the cost structure occurred. However, this was a time-consuming process that was also vulnerable to errors. After launching, the configurator was linked directly to the ERP system of the case company and then automatically updated with the most recent data every 24 hours. This eliminated the need for the time-consuming process of manually updating data and reduced the risk of human error, which can lead to incorrect data in the system.

When any major changes occur in the cost structure of the product-related services in the system or when new variants are added or removed, then both the analysis model and the configurator should be updated accordingly. Similarly, if the case company wishes to include an additional product-related service in the configurator, it should be added as a separate module under the related product life cycle phase. Furthermore, service modules should be defined, constraints and cost models should be formulated, the analysis model should be extended and the new service should be added to the configuration software.

The project for testing the usefulness of the proposed approach to developing and implementing a configurator resulted in a configurator that can generate quotes, including several product variants and specific product-related services for specific customers. It calculates the expected shipping costs for each product variant based on the location of the customer, the sales volume, the dimensions of the product and the product unit order quantity. The configurator developed also computes the cost of alternative, more cost-efficient shipping methods and suggests these to the user. Furthermore, it calculates the cost of repacking products into boxes, marking boxes with custom labels and creating documentation reports. Finally, either a suggested sales price is computed based on a desired target CMR, or an expected CMR is calculated based on a desired sales price. The details of the finalised quotes are presented in a structured manner, making it easy to send offers to customers and record the data into the IT systems of the case company.

5.1.3 Research contribution

Product-related services represent a significant part of the value proposition provided by manufacturing companies and are related to significant costs and complexity levels (Vandermerwe & Rada, 1988). In Study C, the configurator was proposed as appropriate for use as a tool to manage such complexity while simultaneously protecting the business of existing customers. However, as no strategies for developing and implementing configurators for product-related services could be found in the literature, Study C was conducted to develop and test such an approach by modifying existing methods for developing configurators to handle the distinct obstacles related to product-related services.

5.1.3.1 The challenges related to configurators for product-related services

Manufacturing companies usually maintain comprehensive overviews of the products in their portfolio in their ERP systems. However, this may not be the case for the product-related services offered by the company. Therefore, during the scoping phase, the modified approach proposed a systemic analysis and mapping of existing product-related services, followed by a systemic evaluation of existing services to identify the most valuable to include in the scope of the configurator. Creating a comprehensive overview of existing product-related services and then deciding what to include in the scope of the configurator naturally triggered discussions on the existence of non-value adding variety. Based on the insights gained from these analyses, companies may identify and terminate parts of this non-value adding variety.

Another unique challenge related to the configuration of product-related services is that the availability of service variants is directly connected to the choice of customers and products. The proposed approach, therefore, includes a step in which individual product-related service variants are systematically analysed to define how their availability should be limited by customer and product attributes. If these constraints are not defined at a sufficient level of detail, then companies become heavily reliant on the intangible knowledge of employees regarding which product-related services are available for specific products and at specific locations. By defining these constraints, the users of the configurator are no longer required to manually keep track of these limitations. This reduces the risk of losing valuable intangible information when key employees leave the company and makes the training of new employees significantly easier. Furthermore, constraints can be used as a tool to manage the behaviour of sales personnel to meet specific strategic goals. This can be done by restricting the selection of specific product-related service variants to specific groups of customers or by requiring that these customers pay a premium price for these services.

The cost of providing product-related services is directly connected to the choice of customer and product, and the cost drivers differ significantly depending on the type of product-related service. For example, the cost of repacking products into alternative box types is driven by the type of box and the number of units to be packed in each box, while the cost of shipping is driven by the physical dimensions and quantity of products to be shipped in each order, the shipping method and the geographical location of the customer. Therefore, the proposed approach recommends that significant resources be spent to conduct workshops with company experts to identify the specific cost drivers of product-related services to be included in the configurator and to then develop customised cost models based on the identified cost drivers. The potential economic consequences of not developing accurate and customised cost models are further analysed and discussed in the following section.

Finally, the approach proposed extends the analysis model with an additional and separate view containing the product-related services. In this view, product-related services are organised according to the life cycle phase during which they are produced. The modules, attributes, constraints and cost models for each product-related service are gathered into the analysis model that is then used as a tool to guide the programming of the configurator into the chosen configuration software. By organising the product-related services into separate modules and sub-modules, the cost of each service can be calculated separately using the developed cost models. This simplifies the process of extending the configurator with additional product-related services, which should be added as separate modules with their separate sub-modules, attributes, constraints and cost models.

5.1.3.2 Benefits of the proposed approach.

Real order data were collected, validated and used to test and compare the performance of the developed configurator to the performance of the existing manual specification process at the plastic company. Additionally, semi-structured interviews were conducted with company experts and end users to confirm the validity of the data used for the tests and the results achieved from the tests. Additional interviews were conducted to identify other benefits gained from using the new configurator. Four main types of benefits were identified: increased cost transparency, increased service price accuracy, improved possibilities for customer differentiation and more formalised and structured service specifications.

The manual specification process followed before the configurator was developed and deployed only considered direct product costs. The configurator developed uses customised cost models to also consider the costs related to box repacking, labelling, shipping and documentation reports. Hence, by using the configurator, the overall cost pool that price calculations are based on was increased by 14.5%. This increased cost transparency is most impactful in the more extreme offerings, for which the cost of the product-related service equals either much more or much less than 14.5% of the total costs. This is illustrated in the real example presented in Table 5.2. In this example, the product being offered is packed in a type of box of which a single pallet can fit 28. If an offering is created for which only a single box of products is shipped to the customer with each order, the shipping cost would be equal to 142% of the total direct product costs. Using the old specification process, the shipping cost would be assumed to be a fixed rate of 15% of the direct product costs. As illustrated in Table 5.2, if a sales price was calculated based on this cost to hit a target contribution margin of 50%, then the accurate margin would be -5.2% because the actual shipping cost in this example would be much higher. Consequently, when using the manual specification process, the company would risk offering a sales price to the customer based on the assumption that it would ultimately be profitable, but the company would actually lose money on the offering. The opposite case is also possible. If a customer was willing to receive a full pallet of products with each order, the old specification process would overestimate the shipping cost and calculate a sales price based on this information. This sales price may not be competitive, potentially resulting in lost revenue. By employing the cost models developed for the configurator, companies gain increased product-related service price accuracy, thus reducing the risk of offering prices that are calculated based on over- or underestimated costs.

Table 5.2 - Example of the impact of shipping cost on contribution margin ratios in the new and previous configurators

Specification process	Calculated shipping cost	Percentage of product cost	Total cost	Suggested sales price	Actual contribution margin ratio
Product-related service configurator	€ 9.00	142%	€ 15.34	€ 30.68	50.0%
Manual specification process	€ 0.95	15%	€ 7.29	€ 14.58	–5.2%

Another example concerns the cost of documentation reports. The cost of creating a documentation report is fixed and, therefore, does not vary depending on the volume of products sold. This means that if a customer purchases a small number of products, then the relative cost of the documentation report compared to the direct product cost is larger than if the customer purchases a greater number of products. An example of this, using real data, is illustrated in Table 5.2. If a customer purchases 100,000 units of a specific product variant, the cost of the documentation report would be equal to

30.3% of the direct product costs. However, if the customer, instead, purchases 1,000,000 units, the cost of the documentation report would only be 4.2% of the direct production costs. The configurator can account for this link between the sales quantity and the cost of the documentation report to ensure that a suitable sales price is calculated.

Table 5.3 - Example of the impact of sales quantity on documentation report cost

Annual sales quantity	**Direct product cost**	**Cost of documentation report**	**Total cost**	**Cost of documentation report as % of total cost**
100,000	€ 634.00	€ 275.00	€ 909.00	30.3%
1,000,000	€ 6,340.00	€ 275.00	€ 6,615.00	4.2%

The increased cost transparency gained from the customised cost models based on the unique cost drivers of individual product-related services provides the opportunity for defining automatic prompts to assist the configurator user. For example, users can be notified if more cost-efficient service variants exist based on the characteristics of the configuration. These alternatives can then be presented to and discussed with customers. However, this opportunity would not be possible without customised cost models.

The configurator also improves possibilities for customer differentiation. During the first step in the new specification process, the specific customer for whom the quote is made is selected. This enables the configurator to determine which service variants should be offered based on the customer or to enforce specified strategic goals targeted at specific groups of customers. It is possible also to define specific requirements regarding the minimum CMRs for different customer segments. If, for example, penetrating a new market is a strategic priority, lower CMR targets can be required for this market. This governance can be defined in the configurator and then be applied automatically when creating offers.

Finally, the output of the configurator is formalised and structured, containing information regarding product variants, total sales quantities, minimum order quantities and product-related service variants. Such data can be easily recorded in ERP or CRM systems.

Consequently, the case study indicated that the proposed approach for developing and implementing configurators for product-related services was a useful tool for managing product-related service variety while protecting the future business of existing customers.

5.2 *Managing product delivery services*

A common measure of the success of a product delivery service is an assessment of the OTD performance. However, neither the usefulness of the CP-OTD rate nor the use of multiple delivery time windows has received sufficient attention in the literature, despite being meaningful measures. To address this gap, a systematic literature review was conducted as part of Study C to synthesise how OTD performance is defined in the academic literature with a subsequent focus on how CP-OTD has been used as a performance measure. This was followed by a case study to explore how enhancing delivery performance measurement systems using CP-OTD and multiple delivery windows can enable companies to better manage product delivery services and to more accurately identify potential areas of improvement.

5.2.1 Systematic literature review

For the systematic literature review in study D, more than 1,400 articles were extracted from the SCOPUS and Web of Science databases, which have been shown to be comprehensive sources for peer-reviewed literature in the operations management context (Costa et al., 2018; Suzić et al., 2018). The purpose of the literature review was to explore how OTD performance is defined in the academic literature (regarding the use of different comparison dates) and with a subsequent focus on how CP-OTD has been used as a performance measure. Search strings were developed iteratively to include relevant keywords and synonyms for OTD and to limit the results to only articles that discuss product, manufacturing or operational contexts. This was mainly done to exclude irrelevant articles within the fields of electronics and medicine. The search strings used for each database are shown in Table 5.4.

Table 5.4 - Search strings used for Study D literature review

Database	Search string
Scopus	TITLE-ABS-KEY (“on time delivery” OR “delivery performance” OR “delivery reliability” OR “delivery timeliness” OR “order timeliness”) AND TITLE-ABS (“production” OR “manufactur*” OR “operation*”) AND PUBYEAR > 1996 AND (LIMIT-TO (SRCTYPE , “j”)) AND (LIMIT-TO (LANGUAGE , “English”))
Web of Science	(TS=(“on time delivery” OR “delivery performance” OR “delivery reliability” OR “delivery timeliness” OR “order timeliness”) AND TS=(“production” OR “manufactur*” OR “operation*”)) Additional filters: LANGUAGE: (English) AND DOCUMENT TYPES: (Article) AND [excluding] DOCUMENT TYPES: (PROCEEDINGS PAPERS), Timespan: 1996–2021

The search was limited to journal papers, as book chapters and conference papers lack a peer-review process. The range of articles was also limited to those written in English and published after 1995. For each article, the following data were extracted and further processed in a spreadsheet: title, author name(s), publication name, publication year, keywords and abstract. The final extract was made on 26 October 2021.

Journal quality criteria were applied to the sample of articles to narrow the literature selection and identify studies of the highest quality. Only articles from journals ranked in the first or second quartile of the Scimago Index in 2020 within the areas of business management and accounting, engineering, decision science or economics, econometrics and finance were included. Furthermore, duplicate articles were removed from the sample of articles.

Abstract criteria were applied to identify all articles that referred either to quantifying OTD performance, conducting a survey regarding OTD performance and/or discussing the definition of OTD. Furthermore, only articles focused on manufacturing companies were included. Articles that highlighted the OTD performance of internal production orders were also removed, meaning that only articles that addressed customer delivery orders were kept.

Finally, full-text reading was performed on the 284 remaining articles to confirm that the articles met the previously identified criteria. This resulted in a final sample of 182 articles that were then analysed through a meta-synthesis, a technique for thematically analysing and synthesising the literature (Tranfield et al., 2003). Key variables were coded, including research methodology, definition of OTD, comparison date, types and aggregation level of raw data used and whether the article was written from the buyer’s or the supplier’s perspective.

The results of the article selection process are illustrated in Figure 2.1. The initial sample of 1,411 articles was reduced to 182 articles that were analysed in depth.

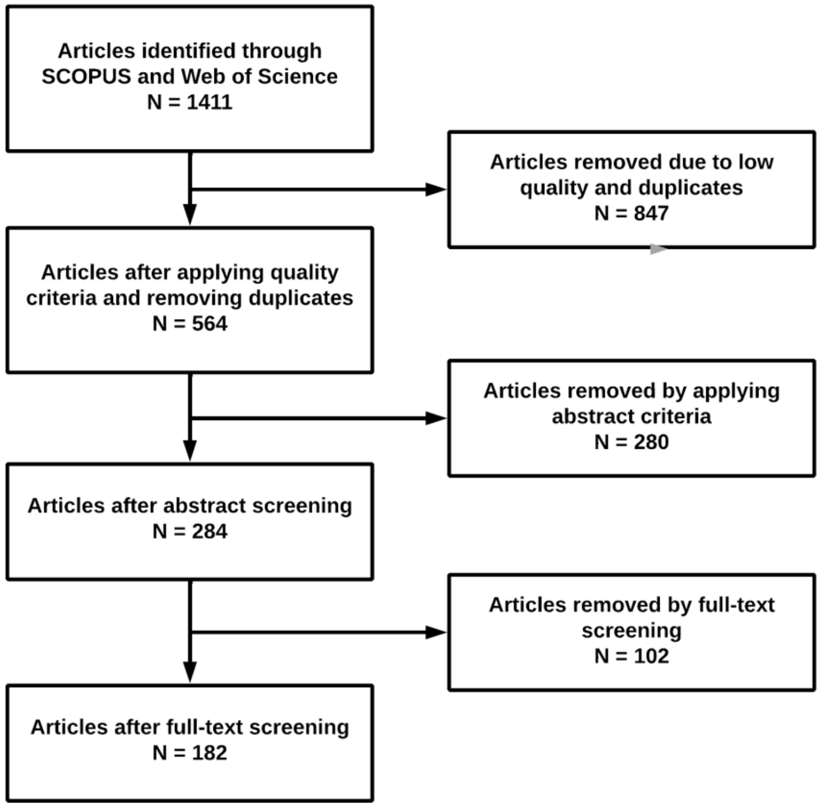


Figure 5.8 - Article selection process (Andersen, Hvam, & Forza, 2023)

5.2.1.1 General description of the identified articles

Various research methods were adopted in the final sample of articles. Surveys were prevalent (44%), followed by modelling papers (34%) and case studies (16%). Several literature reviews (4%) and conceptual papers (2%) were also included.

Types of raw data

Most of the studies described in the articles relied on some type of data analysis. The nature of the raw data used in a study greatly influences the investigation capabilities of the research. The raw data can either be empirical or simulated. Using empirical data allows for a complete description of reality, but it is costly to acquire and difficult to analyse. Using simulated data does not allow for a complete description of the full complexity of reality; however, much noise is removed, and analyses can be very robust. Furthermore, the raw data used can be available at different levels of aggregation. For example, researchers may start their analyses by using data from each individual order line for a given period, including both the promised and actual delivery date. Having access to data at the order-line level allows the researcher complete control of the way that OTD is quantified. Alternatively, researchers may only have access to OTD performance measures at a higher aggregation level, such as for an entire company or for a specific supplier across all order lines. At this level of aggregation, the researchers do not have control of how OTD is quantified and also cannot manipulate the quantification to control for contingency factors at the level of a single company (e.g. different product types or customer segments).

The results of the literature review analysis show that 61% of the articles in the sample documented studies based on empirical data, while 35% documented studies based on simulated data. The remaining 4% described literature reviews that do not use data. The results also show that 22% of the articles referred to the use of real order or order-line level data, while 74% referred to the use of raw data at a higher aggregation level (typically at the plant or company level for a given period). Table 5.5 provides an overview of these results.

Table 5.5 - Types of raw data used in Study D literature review sample articles

Aggregation level of raw data	**Source of raw data**		
	Empirical	**Simulated**	**Total**
Order or order-line level	2%	20%	22%
Aggregation-of-orders level (e.g. plant, company)	59%	15%	74%
Total	61%	35%	96%

Collecting and/or gaining access to real order level data is difficult and time-consuming. For this reason, the fact that only 2% of the identified articles referred to the use of empirical data aggregated at the order level is understandable. These articles all feature case studies.

Contingency factors

In research on OTD, some consider OTD performance related to all orders for a (or of each) company, while others consider subsets of orders based on contingency factors, such as product type or customer group. Of the articles identified, 23% present studies that considered contingency factors. Table 5.6 shows the types of contingency factors considered.

Table 5.6 – Contingency factors considered in the Study D literature review sample articles

Contingency factors	# of papers	Distribution of papers
Suppliers	23	51%
Ways to respond to the market	10	22%
Customer groups	3	7%
Product types	3	7%
Others	6	13%

In this research, the focus was on exploring ways for manufacturing companies to manage their product delivery service while simultaneously protecting the business of their existing customers. Therefore, the articles of greatest interest are those that report on research in which customer groups are considered as contingency factors. However, only three such articles were identified. Of them, only the article from Peng and Lu (2017) refers to the use of real order-level data. This article quantifies the impact of supplier delivery performance on future customer transaction volume and unit price using transaction-level data between a manufacturer of heating, ventilation and air conditioning products and its customers. One of the other articles details a study on the impact of marketing decisions on delivery performance for different markets (Marques et al., 2014), and the other models the impact of dispatching rules on the OTD performance of vital and normal priority customers (Kher & Fry, 2001). Therefore, an opportunity exists to explore ways in which market contingencies can be exploited to identify specific opportunities for companies to manage their product delivery services and to improve their delivery performance.

5.2.1.2 Quantification of OTD

Forslund and Jonsson (2007) presented a framework for quantifying OTD performance, which they argued requires four separate metrics to conduct (see Table 5.7). The first is the *measurement object*, which is the object on which the OTD is quantified. This can be the number of orders, number of order lines, individual items or even turnover. The *time unit* defines the period during which the measurement object must be delivered for the delivery to be considered on time. This is also called the *delivery* time *window* and is referred to as such in the current article. This window can comprise the correct day, the correct week or a more customised time frame (e.g. +1/-2 days). The *measurement point* defines the location along the supply chain at which the measurement object is considered delivered. This can be the point at which the object is shipped from the supplier or when it is received at the customer site. The *comparison date* is the date compared to the time of delivery to determine if the measurement object was delivered on time. For example, this can be the date confirmed by and committed to by the supplier; the delivery date initially requested by the customer is another option.

Table 5.7 - Four metrics required to quantify on-time delivery rate

Metric	**Example**
Measurement Object	Order, order line, individual items, turnover
Time Unit / Delivery Time Window	Correct day, correct week, time window
Measurement Point	When shipped from supplier, when received at customer site
Comparison Date	Supplier-confirmed delivery date, originally customer-requested delivery date

Studying multiple delivery time windows

Modern manufacturing companies often service customers with differing delivery time sensitivities. For some customers, an order that is delivered one day before the promised date is still considered on time, while other customers may prefer not to receive early deliveries. Consequently, the delivery time windows used to evaluate the timeliness of orders should reflect the individual customer's delivery time sensitivity. As such, the use of multiple delivery time windows may be presumed to have been investigated in some depth, even within the same company. However, the results of the literature review show that only five of the identified articles addressed the impact of using multiple delivery time windows. Two of these articles pertain to surveys that asked respondents which delivery time windows they used to quantify OTD. The remaining three are modelling articles that involve the use of simulated data. Thus, no articles were found that referred to the use of real order data to quantify OTD performance using multiple delivery time windows within the same company.

Comparison dates

As previously explained, the comparison date should be defined and specified when quantifying OTD performance (Forslund & Jonsson, 2007). However, the results of the literature review indicate that most articles (59%) do not explicitly specify which comparison date definition is used (see Table 5.11). Of the 75 articles that do explicitly specify the comparison date definition used, 61 mention use of the supplier-confirmed delivery date, while 14 refer to use of the customer's requested delivery date. This indicates that that CP-OTD is understudied in the literature.

Table 5.8 - Comparison date definitions in Study D literature review sample article

Comparison date definition	Number of articles	% of articles
Not specified	107	59%
Supplier-confirmed only	61	34%
Customer-requested included	14	7%
TOTAL	182	100%

5.2.1.3 The use of CP-OTD in the academic literature

As noted previously, 14 articles were identified in the literature review that referred to using the customer's requested delivery date as the comparison date. Six of these articles document studies that used both the customer-requested and the supplier-confirmed delivery dates, while the remaining eight articles document studies that used only the customer-requested delivery date (Table 5.9).

Table 5.9 - Comparison dates used in Study D literature review sample articles that refer to use of customer-perceived on-time delivery

Comparison date	Number of articles	% of articles
Customer-requested only	8	57%
Both supplier-confirmed and customer-requested	6	43%
TOTAL	14	100%

In Table 5.10, the 14 articles from the Study D literature review sample that refer to using the customer's requested delivery date as the comparison date are compared on relevant parameters. As this table reveals, five of the articles do not specify the measurement object being used, two do not specify the delivery time window and three do not specify the measurement point. Furthermore, only two articles mention using multiple measurement objects, delivery time windows and measurement points: both were authored by Forslund and Jonsson (2007, 2010). In addition, most (eight) of the articles describe studies that did not involve the use of multiple units of analysis within the same company, while only two articles referred to examining OTD performance for multiple product types, and only four refer to studying OTD performance for multiple suppliers.

Various research methods were described in the 14 articles, namely, surveys, case studies and modelling, along with a single literature review. Moreover, seven articles focus on studies in which real raw data were used, while six focus on studies in which simulated data were used. The studies outlined in four articles used raw data at the order level, while the research highlighted in nine articles referred to the use of raw data synthesised at a higher aggregation level. Only one article addressed using real raw data at the order level.

Table 5.10 - Dimensions of the 14 articles (Andersen, Hvam, & Forza, 2023)

Author(s)	**Research Method**	**Measurement Object**	**Delivery Time Window**	**Measurement Point**	**Comparison Date**	**Source of Raw Data**	**Aggregation Level of Raw Data**	**Contingency Factor**
Tenhiälä et al., 2018	Survey	Not specified	One	Not specified	Requested & Confirmed	Real	Aggregation-of-orders level	None
Forslund & Jonsson, 2007	Survey	Multiple	Multiple	Multiple	Requested & Confirmed	Real	Aggregation-of-orders level	None
Forslund & Jonsson, 2010	Survey	Multiple	Multiple	Multiple	Requested & Confirmed	Real	Aggregation-of-orders level	None
Forslund & Mattsson, 2021	Survey	Not specified	Not specified	Delivery at customer site	Requested & Confirmed	Real	Aggregation-of-orders level	None
Knoblich et al., 2015	Modelling	No. of items	One	Delivery at customer site	Requested & Confirmed	Simulated	Order level	Product types
Gunasekaran et al., 2001	Literature review	Not specified	Not specified	Delivery at customer site	Requested & Confirmed	N/A	N/A	None
Sawik, 2010	Modelling	Orders	One	Shipment from supplier	Requested	Simulated	Aggregation-of-orders level	Suppliers
Choudhary et al., 2006	Modelling	Order lines	One	Delivery at customer site	Requested	Simulated	Order level	None
Garg et al., 2006	Modelling	Order lines	One	Delivery at customer site	Requested	Simulated	Order level	Suppliers
Karpak et al., 1999	Modelling	Not specified	One	Not specified	Requested	Simulated	Aggregation-of-orders level	Suppliers
Terwiesch et al., 2005	Case study	Order lines	One	Delivery at customer site	Requested	Real	Aggregation-of-orders level	None
Heim et al., 2014	Case study	Order lines	One	Shipment from supplier	Requested	Real	Order level	Product types
Robertson et al., 2002	Case study	Not specified	One	Not specified	Requested	Real	Aggregation-of-orders level	None
Shin et al., 2009	Case study	No. of items	One	Delivery at customer site	Requested	Simulated	Aggregation-of-orders level	Suppliers

Considering the customer-requested date as the comparison date has the potential to lead to interesting insights into various OTD contingencies, specifically with reference to various customer groups. However, of the 14 articles from the Study D literature review sample refer to using the CP-OTD, only two address the impact of using multiple delivery time windows, only six consider both the customer-requested and supplier-confirmed delivery dates, only one mentions the use of real order-line level data in the research and none refer to the effect of using different customer groups as contingency factors. Thus, much potential still exists for enquiries into ways to exploit the metrics presented by Forslund and Jonsson (2007).

To understand potential ways to approach this line of enquiry, Study D considers in detail the content of the 14 articles that consider CP-OTD (see appendix for full text). To summarise, the CP-OTD was indicated as being used significantly in the industry, as data on Swedish companies report that 25–28% of companies use this measure of OTD performance (Forslund & Jonsson, 2010; Forslund & Mattsson, 2021). Moreover, only a single article was found that quantifies both CP-OTD and SC-OTD using the same set of orders and discusses the differences in the results (Knoblich et al., 2015). However, this article is based on simulated data within a specialised supply chain setup that is regulated by pre-agreed contracts between the buyer and supplier. The focus of the article is on evaluating the performance of various contract types and, therefore, not on managerial insights into the use of CP-OTD and SC-OTD.

5.2.2 Conclusion on systematic literature review

Although the relevance of the CP-OTD is clearly evident through its use in practice and its use in the studies described in the 14 articles that consider CP-OTD in the literature, the specific value of the CP-OTD is still under investigated. In particular, the literature lacks empirical evidence that identifies ways CP-OTD can be used and what value a company can receive from its use. Given that the most used measure of OTD seems to be SC-OTD, gaining insights into the use of CP-OTD is better achieved by relating to the SC-OTD than by studying the CP-OTD in isolation.

Furthermore, the literature on OTD performance in general pays only limited attention to customer groups as contingency factors (and surprisingly, no studies do this using empirical order level data). A similar scarcity of research exists regarding the impact of using different delivery time windows, as no publications were found that referred to studies that used empirical order level data. Finally, the potential for researching OTD using empirical data at the single order-line level has not been tapped.

Therefore, a decision was made to contribute to the literature in this area by empirically investigating how the CP-OTD and SC-OTD can be jointly used to measure OTD performance and to assess OTD performance adequacy in satisfying different customers' needs to identify improvement opportunities, through a case study at the site of the plastic company. The framework presented by Forslund and Jonsson (2007) was used as the basis for defining the OTD quantifications made in the case study.

5.2.3 Case study

For a company to quantify CP-OTD, it must first register the customer-requested delivery dates for individual orders. Additionally, for an analysis of this to elicit useful insights, the data must be collected over an extended period. Prior to this case study, the plastic company did not keep records of such data. When an order was received in the ERP system, the customer-requested delivery date was entered. However, this data was subsequently overwritten with the supplier-confirmed delivery date. Therefore, following the case study, the process was changed so that the initially requested delivery date was recorded in a separate data field in the ERP system that was never to be overwritten. The supplier-confirmed delivery date was then recorded separately.

The order process followed by the plastic company is illustrated in Figure 5.9. A customer would submit a purchase order request detailing the product variant(s) and quantities desired, along with a customer-requested delivery date. This order was received at the case company, and the initially requested delivery date was recorded. The case company then evaluated the order request. If the request was confirmed, an order confirmation was generated and sent to the customer, and the confirmed delivery date was recorded in the ERP system. If the request was declined, an alternative order delivery date was generated and suggested to the customer, which started a loop in the process. First, the customer evaluated the alternative order delivery date suggestion, and if it was acceptable, an order confirmation was generated for the case company, and the confirmed delivery date was recorded in the ERP system. If the suggestion was declined, the order was either cancelled and the process stopped, or a modified order request was generated and sent to the case company, starting the evaluation loop again. Note, however, that the requested delivery date was only recorded in the ERP system at the first instance of the loop.

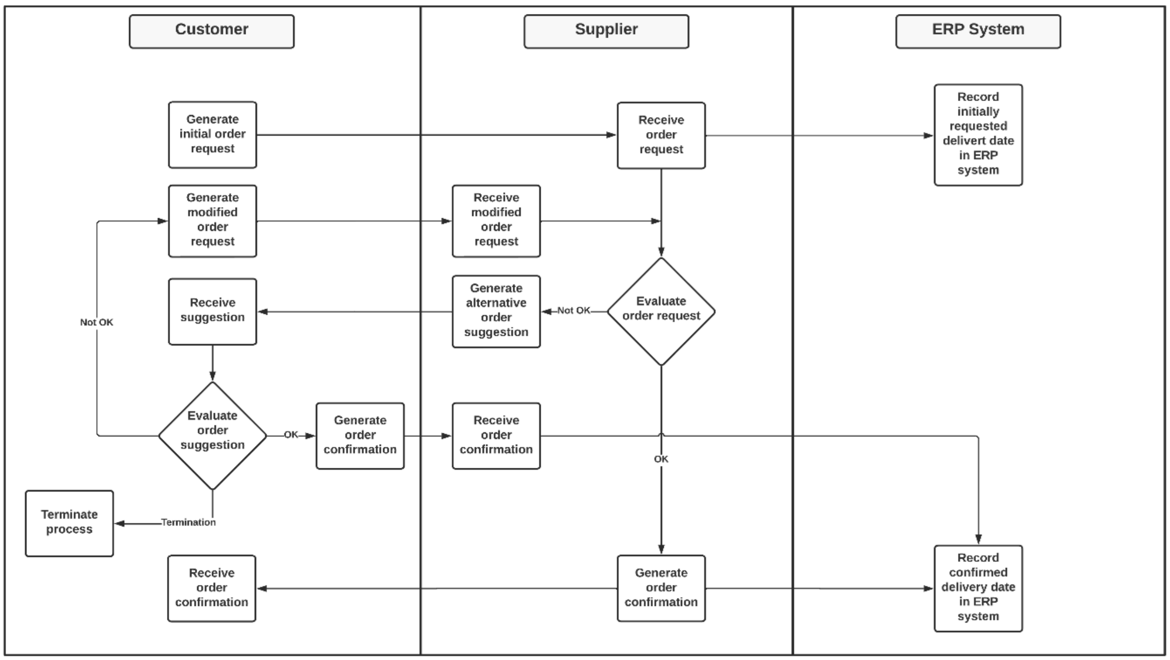


Figure 5.9 - Ordering process of the case company (Andersen, Hvam, & Forza, 2023)

The case study was conducted based on a set of 47,323 sales order lines extracted over a 12-month period from June 2020 to May 2021. All order lines were shipped from the main distribution centre in Europe.

5.2.3.1 Definition of metrics used to quantify OTD in the case study

As explained by Forslund and Jonsson (2007), four metrics need to be specified when quantifying OTD. The following metrics were used in the case study.

Measurement object

In the data, some orders consisted of several order lines of the same product variant that were requested for delivery on different dates. Therefore, an order line was defined as a unique product variant in a unique order requested to be delivered on a unique date. This is illustrated in Table 5.11

Table 5.11 - Example of order line definition.

Customer ID	Product ID	Requested delivery date	Note
AB001	XY001	01.07.2020	Unique order line, as the requested dates differ
AB001	XY001	15.07.2020	
AB001	XY002	15.07.2020	Unique order line, as the product IDs differ

Measurement point

Agreements were made with the customer regarding the date that each order was to be delivered at the customer site. However, collecting such data accurately was not plausible. The case study was conducted from the supplier's perspective and was based on data extracted directly from the ERP system. Therefore, the customer-requested, supplier-confirmed and actual shipping dates were used as the measurement points. The shipping date is simply the delivery date minus the shipment time.

$$shipping\ date = delivery\ date - shipment\ time$$

Delivery time window

The delivery time window defines the period during which an order must be delivered for the delivery to be considered on time. One of the purposes of the case study was to study the impact of using different delivery time windows depending on the heterogenous delivery time sensitivity of different customers. Therefore, six delivery time windows were used in the case study. These are presented in Table 5.12.

Table 5.12 – The six delivery time windows used in the case study

Delivery time window	Description
[0]	Delivery on exact date
[-1;0]	Delivery between 1 day early and the exact date
[-1;1]	Delivery between 1 day early and 1 day late
[-1;2]	Delivery between 1 day early and 2 days late
[-∞;0]	Delivery on exact date or earlier
[-∞;1]	Delivery up to 1 day late or earlier

Partial deliveries

When quantifying OTD performance, whether partial deliveries are allowed must be determined. For example, consider an order of 100 units that is split into two separate shipments of 90 and 10 units. If only the first shipment is shipped on time, is the order, then, 90% on time? Or should we consider the entire order not on time? For the case study, a decision was made not to allow for partial deliveries, meaning that if the quantity of products delivered in an order line did not equal the quantity of products ordered, then the whole order line was considered untimely.

5.2.3.2 Results of the case study

This section presents the results of quantifying the OTD rate with the extracted set of order data using the previously specified OTD metrics.

SC-OTD vs. CP-OTD

The analyses were based on a total of 47,323 order lines. Of these, 10,279 (21.7%) were not delivered on the supplier-confirmed date, and 19,107 (40.2%) were not delivered on the customer-requested date. Figure 5.10 shows the distribution of these order lines according to the number of days between the supplier-confirmed/customer-requested date and the shipping date. The order lines are divided into several groupings. Between -5 and 5 days, each grouping consists of only a single day. Outside this range, the x-axis changes scale to include several days in each grouping. Note that orders shipped on the exact confirmed shipping date are not shown in this graph because displaying those details would make the rest of the data unreadable.

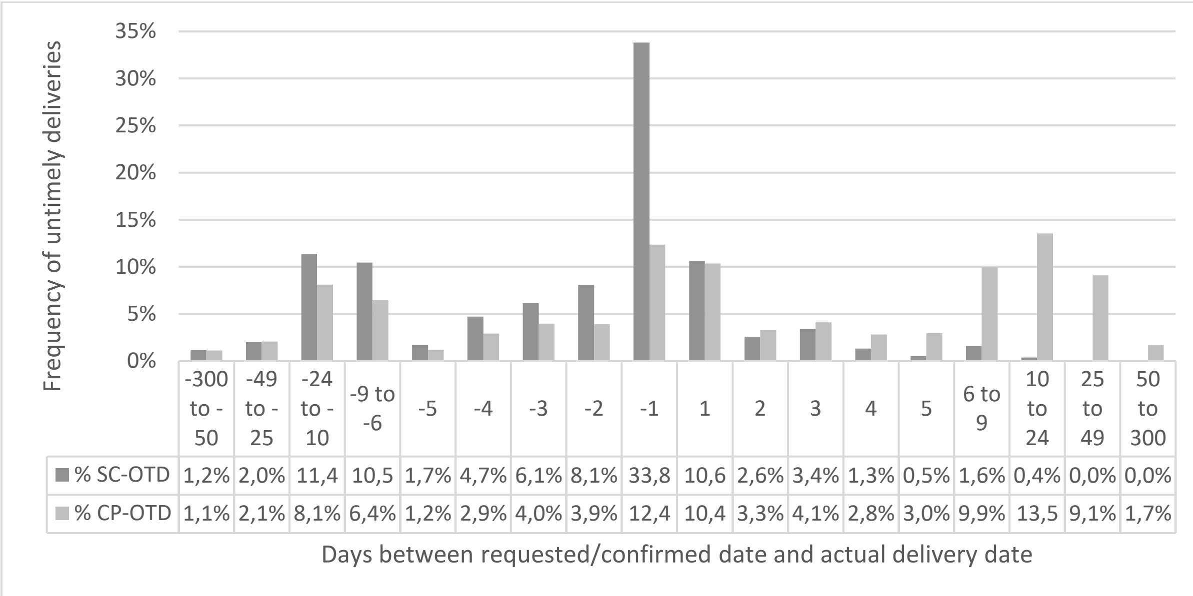


Figure 5.10 - Distribution of untimely deliveries according to customer-requested and supplier-confirmed dates, adapted from (Andersen, Hvam, & Forza, 2023)

Figure 5.10 illustrates that the company sought to ship orders with only minimal delay in relation to the supplier-confirmed shipping date and, to a large extent, allow orders to be shipped prior to the supplier-confirmed shipping date. However, the opposite pattern emerges regarding the customer-requested shipping date. Here, orders were delivered late in more cases than they were delivered early.

If all customers had homogenous delivery time sensitivities, then Figure 5.10 would provide a good indication of how well the company was able to deliver on what the customer initially requested and on what it ultimately promises to its customers. However, the case company served two main customer segments with differing delivery time sensitivities. One segment operated with JIT production, resulting in an increased aversion towards early deliveries, whereas the second segment was, for the most part, not sensitive to early deliveries. Consequently, the timeliness of orders shipped to customers within these segments should be evaluated differently, using distinct delivery time windows. Therefore, the graph in Figure 5.10 does not provide an accurate picture of OTD performance in the company. Therefore, the analyses need to be extended by using customer groups as contingency factors to more accurately assess OTD performance and to identify specific improvement possibilities and elicit insights into how to best manage the product delivery service.

However, before going into a deeper analysis regarding the use of customer groups as contingency factors, an interesting detail to consider is how the selection of delivery time windows affects the quantification of OTD performance. Figure 5.11 shows the SC-OTD and CP-OTD for the case data when using six delivery time windows. This graph illuminates the fact that the selected delivery time window heavily influences the results of the OTD quantification for both the SC-OTD and CP-OTD, especially the determination on how to handle early deliveries. This further emphasises the importance of using customer groups as contingency factors for customers with heterogenous delivery time sensitivities. Another finding conveyed in Figure 5.11 is that a significant gap between SC-OTD and CP-OTD existed across all six delivery time windows (between 17.3 and 21.5 percentage points). This indicates that the company was, in many instances, unable to meet the initial requests of its customers, while it was more capable of meeting the delivery date that it confirmed to the customers. This indicates that a significant improvement potential exists for increasing customer satisfaction by improving the CP-OTD. Previously, the delivery performance measurement system of the company only quantified SC-OTD. By enriching the performance measurement system with CP-OTD, the company can start to reflect on the gap between the two measures to identify possible areas for improvement.

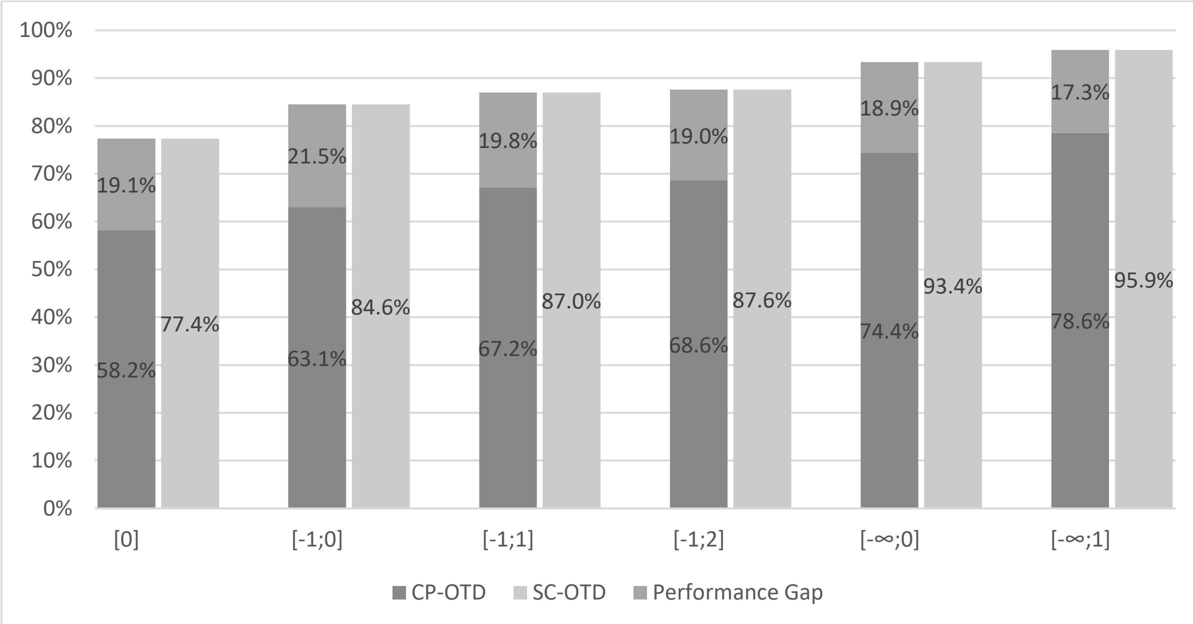


Figure 5.11 – Customer-perceived on-time delivery rate vs. supplier-confirmed on-time delivery rate using various delivery time windows (Andersen, Hvam, & Forza, 2023)

Market contingencies

Because the company served customers with heterogenous delivery time sensitivities, the analyses were enhanced through the use of customer groups as contingency factors. The purpose was to obtain insights into how to more accurately assess the OTD performance of heterogeneous groups of customers, thereby identifying segments, markets or individual customers with improvement potential, as well as gathering insights into how to better manage the product delivery service for groups of customers with heterogenous needs.

Customer segments

As previously explained, the company served two main customer segments. Due to confidentiality concerns, the exact nature of the customer segments is not specified. Segment A contributed to 57% of the order lines in the dataset, while Segment B contributed to 42%. The remaining 1% of order lines were split across two minor segments that were not further analysed. The fraction of order lines that were confirmed exactly to the customer-requested date differed significantly between the two segments, with Segment B having a significantly larger fraction of orders confirmed for the customer-requested date (see Figure 5.12). This may mean either that the requests of Segment A were more reasonable and, therefore, easier to accept or that the company prioritised the service of customers within this segment. Alternatively, the difference may be an indication that the supply chain of the company was better suited for meeting the needs of Segment A.

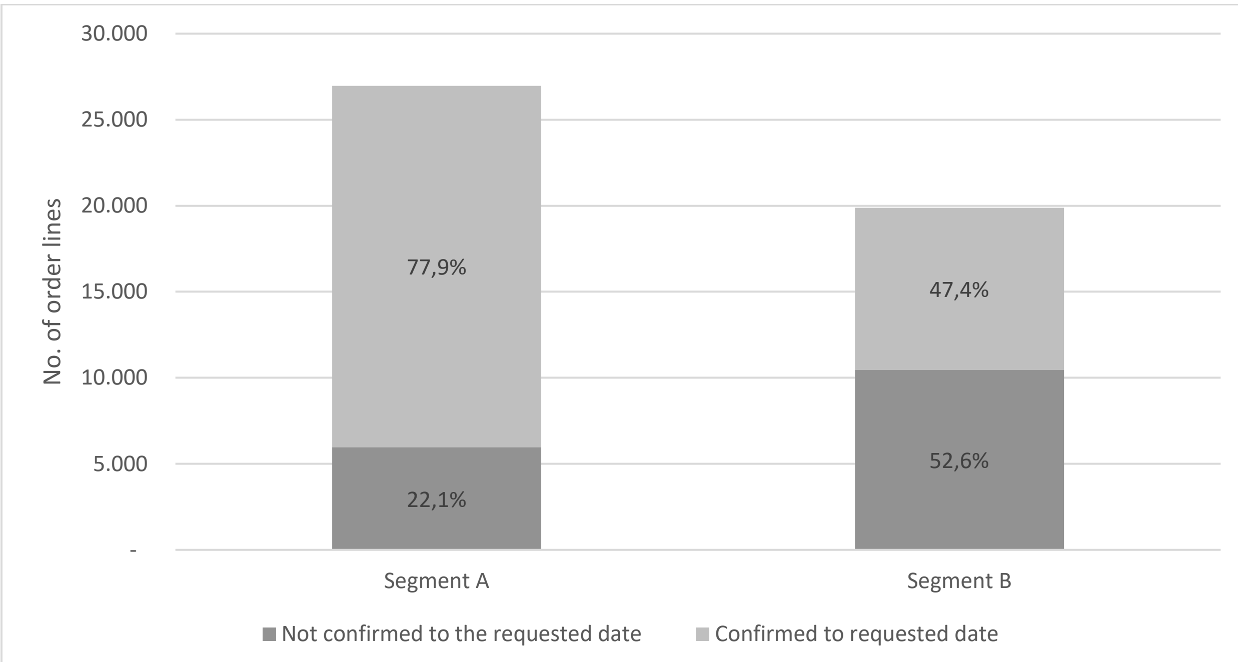
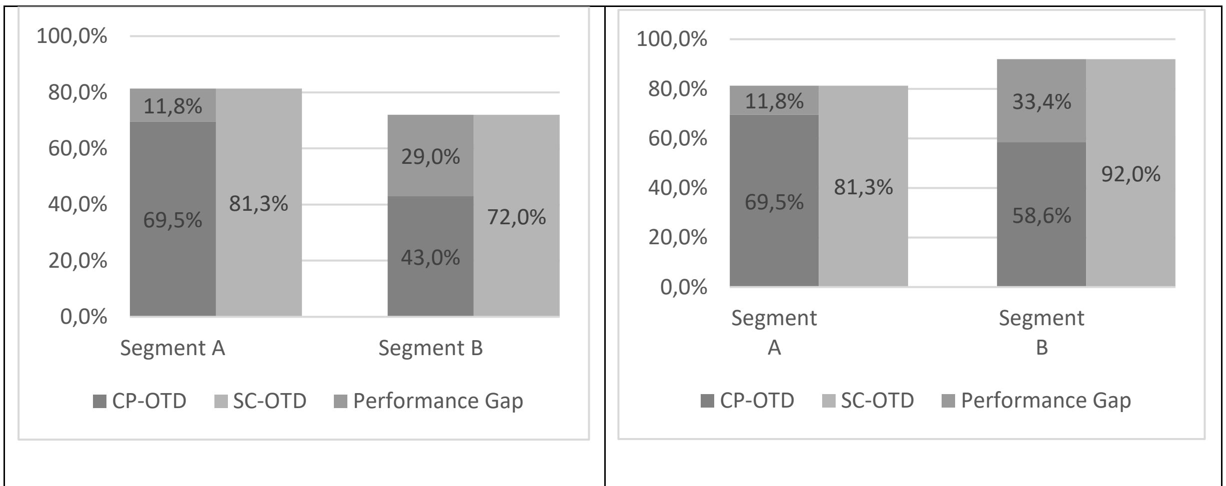


Figure 5.12 - Distribution of order lines confirmed to and not confirmed to the customer-requested date for Segments A and B (Andersen, Hvam, & Forza, 2023)

As previously illustrated, the selection of delivery time window has the potential to heavily influence the results of the OTD quantification. In this company, as in many other companies, the same delivery time window was used to evaluate the timeliness of all orders, and the delivery time window being used was the most restrictive. However, in this case, Segment A and B customers had differing delivery time sensitivities. Segment A did not tolerate early deliveries, so the timeliness of their orders was evaluated using the delivery time window [0], meaning that only orders that were shipped on the exact correct date were considered on time. Segment B, however, did not mind early deliveries, so the timeliness of their orders was evaluated according to the delivery time window [-∞;0], meaning that early orders were considered to be on time. The left section of Figure 5.13 shows the SC-OTD and CP-OTD of the two customer segments when using the most restrictive delivery time window, while the right section shows the same but using the appropriate delivery time windows for each segment. The differences between the two sets of results significant. When evaluating OTD performance using the restrictive delivery time window, the overall service provided to Segment B appears to be at the lowest level, and the gap between the SC-OTD and CP-OTD appears to be largest for Segment B. This can lead managers to launch initiatives to improve the product delivery service provided to Segment B in an effort to increase customer satisfaction. However, when evaluating OTD performance using the appropriate delivery time windows, Segment B actually receives much better service than initially indicated. This illustrates the importance of using appropriate delivery time windows to evaluate the OTD performance of customers with heterogenous delivery needs.

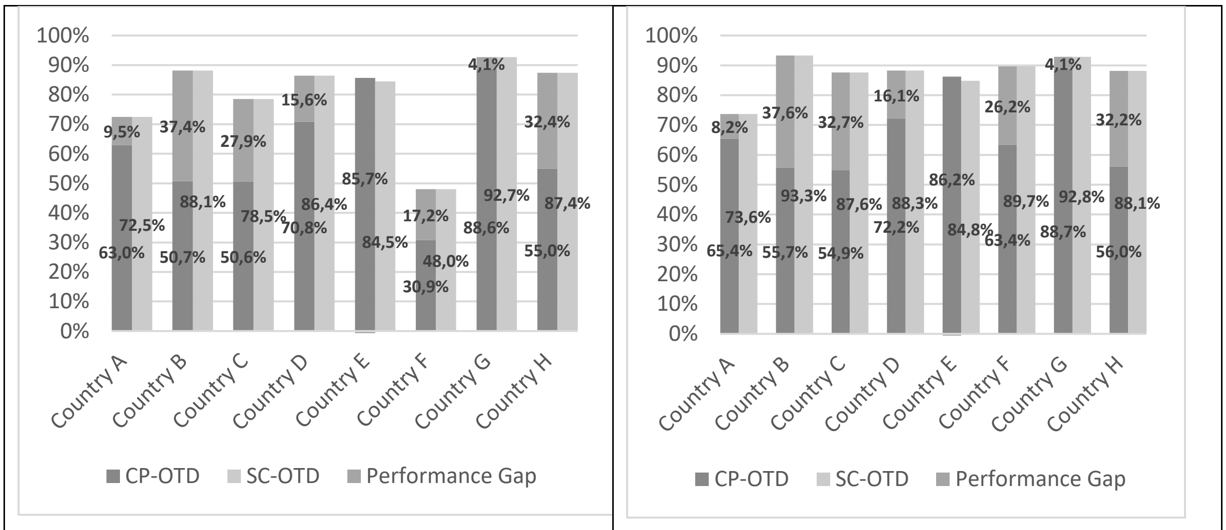


OTD performance using the most restrictive delivery time window	OTD performance using the appropriate delivery time windows

Figure 5.13 - Customer-perceived on-time delivery rate vs. supplier-confirmed on-time delivery rate by customer segments using the most restrictive or most appropriate time windows (Andersen, Hvam, & Forza, 2023)

Countries

A similar analysis was conducted using countries as contingency factors. The left section of Figure 5.15 shows the SC-OTD and CP-OTD when using the most restrictive delivery time window for the eight countries with the highest number of order lines. The right section of the figure shows the same but using the appropriate delivery time windows according to the customer segment to which each individual customer in each country belonged. The results further emphasise the importance of using appropriate delivery time windows to evaluate the OTD performance of customers with heterogeneous delivery needs. The results for Countries B, F and H are especially interesting, as their CP-OTD indicates satisfactory levels of service. However, they each have a performance gap of more than 30 percentage points between SC-OTD and CP-OTD, indicating a significant potential for improvement within these countries. This improvement potential only becomes visible by quantifying both SC-OTD and CP-OTD while using appropriate delivery time windows.



OTD performance using the most restrictive delivery time window	OTD performance using the appropriate delivery time windows

Figure 5.14 - *Customer-perceived on-time delivery rate vs. supplier-confirmed on-time delivery rate by country using the most restrictive and the most appropriate delivery time windows* (Andersen, Hvam, & Forza, 2023)

Individual customers

Finally, a similar analysis was conducted using individual customers as contingency factors. The appropriate delivery time windows were collected for six of the largest customers (measured in number of order lines). The top section of Figure 5.15 shows the SC-OTD and CP-OTD of each customer using the most restrictive delivery time window, while the bottom section shows the same but using the appropriate delivery time windows to reflect the delivery sensitivity of each individual customers. Figure 5.15 depicts that Customers C, D and F represented very different situations. Customer C received the lowest SC-OTD but had almost no performance gap with respect to CP-OTD, while Customer D received highest SC-OTD rate and had the largest performance gap in relation to CP-OTD. According to the SC-OTD, Customer D received excellent service, but when also considering the service provided according to the CP-OTD rate, this customer was determined to be under serviced. This improvement potential only becomes visible by evaluating both SC-OTD and CP-OTD. The reasons for these results are further analysed and specific improvement initiatives are discussed in Study D (see appendix for full text).

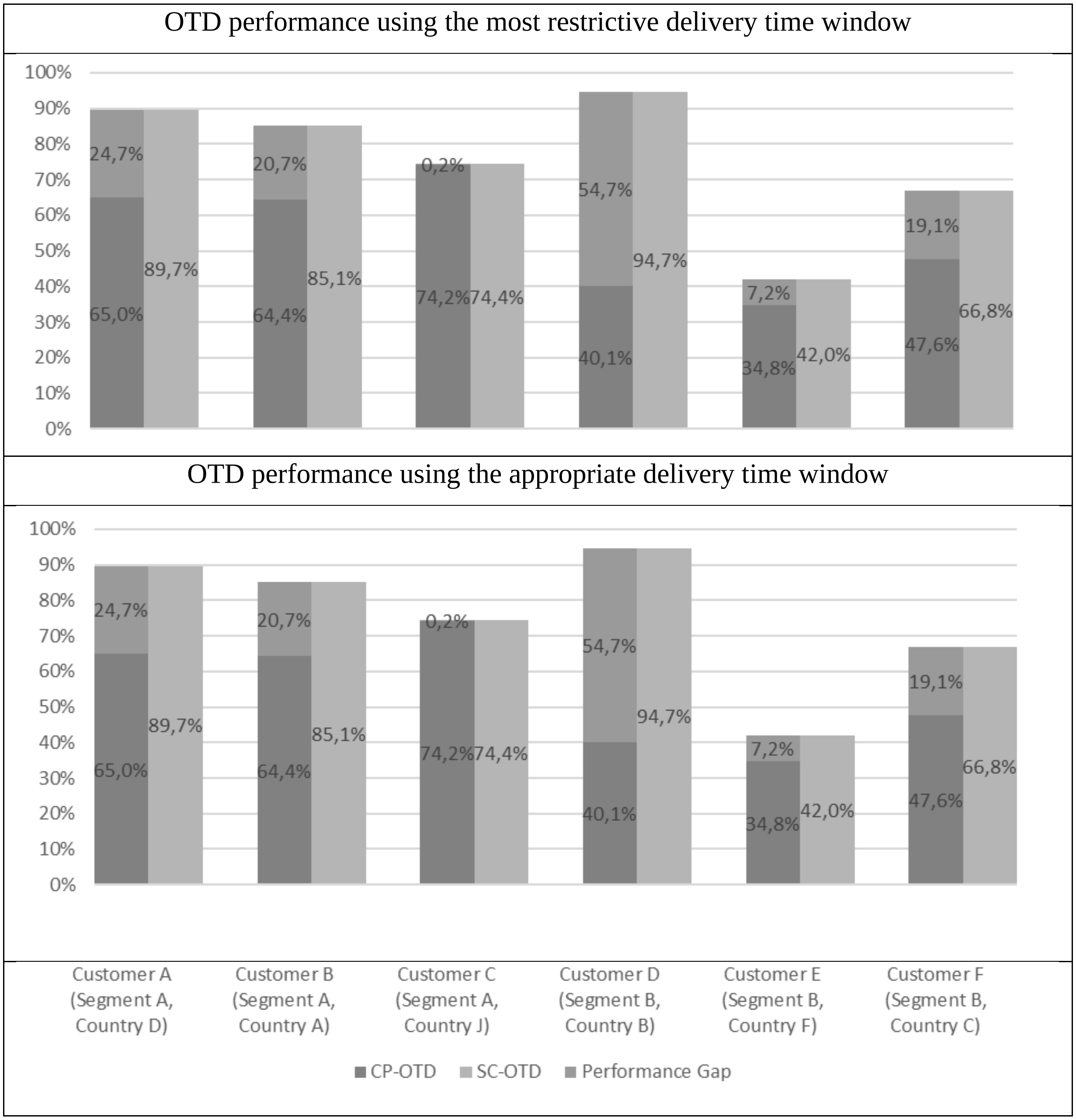


Figure 5.15 - *Customer-perceived on-time delivery rate vs. supplier-confirmed on-time delivery rate by customer using the most restrictive and the most appropriate delivery time windows* (Andersen, Hvam, & Forza, 2023)

Joint analysis of customer-requested, supplier-confirmed and shipping dates

So far, analysing the SC-OTD and CP-OTD simultaneously has provided valuable insights, especially when also considering customer groups as contingency factors. However, the relation between the customer-requested and supplier-confirmed delivery dates of individual orders has yet to be analysed. This connection may be important when evaluating the SC-OTD and CP-OTD and may provide insights into areas for potential improvement and initiatives to improve the management of product delivery services. To explore the potential of such an analysis, Table 5.13 was developed. Here, order lines are classified according to the joint comparison of the shipping date, the customer-requested date and the supplier-confirmed date. Each comparison is categorised as either 'earlier', 'exactly on' or 'after'. Additionally, the order lines are divided into Customer Segments A and B (with the two smaller segments omitted from the analysis). Impossible combinations are marked with a '-'. This table allows us to compare the evaluation of OTD performance within two segments that differ in what they consider satisfactory in terms of the combination of customer-requested, supplier-confirmed and shipped dates. This 'satisfaction' is indicated by the symbols under the number in each cell. Various insights were gained from the analysis of this table.

Firstly, the fraction of order lines that were confirmed for shipping exactly on the customer-requested date and then shipped on this exact date was significantly higher for Segment A (67.8%) than for Segment B (41.0%). Furthermore, the fraction of order lines that were confirmed for a date later than the customer-requested date and then shipped on the supplier-confirmed date was larger for Segment B (26.8%) than for Segment A (7.3%). This indicates the existence of a trade-off between serving the two segments, as meeting the customer-requested shipping date for the most delivery time sensitive Segment A seemed to be prioritised more often, resulting in a lower level of service for Segment B.

Secondly, a significant fraction of order lines were confirmed to be shipped on exactly the customer-requested date but, instead, were shipped earlier (8.7% for Segment A and 7.8% for Segment B). Potential reasons for shipping order lines early include optimisation of warehouse operations, grouping of order lines to reduce logistics costs or freeing up inventory space.

Customers in Segment B did not mind early deliveries, meaning that handling orders in this way did not result in reduced customer satisfaction. However, customers in Segment B did not tolerate early deliveries. Consequently, shipping orders earlier than requested could lead to dissatisfaction for these customers. Therefore, the potential exists to increase the satisfaction of customers in Segment A by ensuring that order lines to these customers are not shipped early, whereas this process should be continued for order lines to customers in Segment B.

Thirdly, the fraction of order lines that were confirmed to be shipped on a date after the customer-requested date that were then shipped on a date before this supplier-confirmed date was 4.8% for Segment A and 11.5% for Segment B. Furthermore, the fraction of orders that were confirmed to be shipped on a date earlier than the customer-requested date was 8.5% for both segments. However, the fraction of these order lines that were then shipped on a date earlier or exactly on the initially requested date was 7.0% for Segment A and 12.6% for Segment B. These results indicate that the customer-requested date was kept in consideration in the operations of the company, as in a significant number of cases attempts were made to meet the initially requested date, even if the orders were confirmed to a different date. If this interpretation is correct, then a manual process of prioritising orders must have existed outside the ERP system because no formal process existed inside the ERP system. However, the difference in delivery time sensitivity between the customer segments becomes important here. Customers in Segment B did not mind early deliveries; therefore, any time the case company shipped an order closer to the customer-requested date when it was confirmed to a later shipment date, the satisfaction of these customers would increase. However, this was not always the case for customers in Segment A. If their requested shipment date was not confirmed, these customers might adjust their production plans to fit with the new confirmed shipment date. Shipping an order line before the confirmed date in an attempt the meet the initial requested shipment date then could lead to customer dissatisfaction. Nevertheless, the delivery of some order lines may be critical to the extent that adjustments of customers' production plans are not possible. In these cases, shipping an order before it was confirmed would be preferred by the customers. Therefore, it would be valuable for the case company to collect the appropriate delivery time windows for individual orders. For example, most order lines for customers in Segment A would use the delivery time window [0], indicating that they preferred the order not to be shipped early. At the same time, some orders from the same customers would use the delivery time window [$-\infty$,0], indicating that the shipment of this order was critical and should, therefore, be delivered as early as possible. Hence, the potential exists to use the now recorded and stored customer-requested delivery date in the ERP system to develop an automated process to identify order lines with a confirmed date different from the customer-requested date and to then, if possible, prioritise deliveries of these order lines to more closely match the customer-requested date. By also collecting the appropriate delivery time window for individual order lines, the usefulness of such a process would be further improved.

Table 5.13 - Distribution of order lines based on customer-requested, supplier-confirmed and shipping dates (Andersen, Hvam, & Forza, 2023)

Percentages of total order lines of each customer segment			**CONFIRMED DATE HAS BEEN in relation to the customer-requested date**						**Total**	
			Earlier		**Exact**		**After**			
			Split by Customer Segment							
			A	***B***	***A***	***B***	***A***	***B***	***A***	***B***
SHIPPING DATE HAS BEEN in relation to the supplier-confirmation date	**Earlier**	**in relation to the customer-requested date: Earlier**	0.7 - -	2.1 + +	8.7 -	7.8 + +	0.4 -	0.8 +	9.9	10.7
		Exact	-	-	-	-	3.0 **?**	3.2 +	3.0	3.2
		After	-	-	-	-	1.5 **?**	7.5 +	1.5	7.5
		Total	*0.7*	*2.1*	*8.7*	*7.8*	*4.8*	*11.5*	*14.3*	*21.4*
	Exact	**Earlier**	7.2 +	5.2 + +	-	-	-	-	7.2	5.2
		Exact	-	-	67.8 + +	41.0 + +	-	-	67.8	41.0
		After	-	-	-	-	7.3 +	26.8 +	7.3	26.8
		Total	*7.2*	*5.2*	*67.8*	*41.0*	*7.3*	*26.8*	*82.2*	*73.0*
	After	**Earlier**	0.3 - -	0.6 **?**	-	-	-	-	0.3	0.6
		Exact	0.3 -	0.5 **?**	-	-	-	-	0.3	0.5
		After	0.0	0.1 - -	2.5 - -	1.9 - -	0.4 - -	2.5 - -	3.0	4.5
		Total	*0.6*	*1.2*	*2.5*	*1.9*	*0.4*	*2.5*	*3.5*	*5.6*
Total			8.5	8.5	79.0	50.7	12.5	40.8	100.0	100.0

\+ + Completely satisfied — - - Completely dissatisfied — ? Situation-specific satisfaction
\+ Mostly satisfied — - Mostly dissatisfied

5.2.3.3 *Implications for the case company*

When managers were presented with the results of the analyses, they were both surprised and intrigued. Moreover, several opportunities for better managing the product delivery service were identified, discussed and initiated.

The analyses showed the significant impact on OTD performance caused by the choice of delivery time window. Therefore, initiatives were launched to collect data on the delivery time sensitivity of individual customers. Evaluating the timeliness of orders according to the customers' individually appropriate delivery time windows will enable the company to more accurately quantify OTD rates and more precisely identify groups of customers with improvement potential.

The joint analysis of the customer-requested, supplier-confirmed and shipping dates of individual orders split between customer segments showed that the satisfaction of customers depended heavily on their delivery time sensitivities. Consequently, initiatives were launched to further analyse the specific delivery needs of different groups of customers in order to modify and customise the product delivery process to better satisfy the heterogenous needs of different customers.

Finally, managers were surprised to learn that some of the most important customers were served at acceptable levels according to the SC-OTD but were receiving a much worse level of service according to the CP-OTD. The company relied heavily on the business of these customers; therefore, projects were undertaken to prioritise the confirmation of these customers' delivery requests in an attempt to increase the CP-OTD and, thus, customer satisfaction. The goal being to protect and grow the business of these customers.

5.2.4 Research contribution

Using a supplier's confirmed delivery date to quantify OTD performance provides a useful internal operational measure of a company's ability to meet its delivery promises to its customers. Using the customer-requested delivery date to quantify OTD performance provides a more direct measure of a company's ability to satisfy the needs of its customers. Although these are both valuable performance metrics, they each measure different aspects of OTD performance. Study D calls for developing and using appropriate, combined analyses of these aspects of OTD performance to help managers identify specific opportunities to improve their company's delivery performance.

The systematic literature review showed that most articles do not specify which comparison date is used, thus complicating the accurate interpretation, comparison and replication of the studies. If a case study was conducted and an improvement in OTD performance was achieved, whether this improvement was achieved using the customer-requested or supplier-confirmed delivery date as the comparison date must be specified. This is also an issue when conducting surveys asking respondents to assess OTD performance. If a survey asks respondents to rate their OTD performance compared with that of their competitors, specifying whether it is measured using the

CP-OTD or the SC-OTD is essential. Of the articles from the literature review that do specify the comparison date used, only a few used the customer-requested delivery date and even fewer discuss or quantify the OTD rate using both the customer-requested and supplier-confirmed delivery dates. Furthermore, of the articles that use or discuss the customer-requested delivery date as the comparison date, only a few study the impact of using different delivery windows, and none study the impact of using customer groups as contingency factors.

The case study conducted at the site of the plastic company was intended to explore how the addition of CP-OTD considerations to delivery performance measurement systems can lead to valuable insights regarding the identification of specific areas with improvement potential and regarding ways for manufacturing companies to better manage their product delivery services. The results show that OTD performance varies greatly across different delivery time windows and comparison dates. In other words, with the same data, we can obtain different OTD performance outcomes, depending on the choice of delivery time window and comparison date. Therefore, simply stating that an OTD rate of 75% or 95% was achieved is not meaningful because the significance of those percentages depends on the metrics used for quantification. Using a single generic number is too limited a view of OTD performance. An improved view can be achieved by using the appropriate different delivery time windows for different customers and both the customer's requested delivery date and supplier's confirmed delivery date as the comparison dates. The case study also shows that when managers were presented with these results, they recognised ways to exploit these insights for economic value, and various initiatives were implemented to capitalise on these insights.

The case study also showed the impact on OTD performance ratings caused by using different delivery time windows. By evaluating the timeliness of orders based on delivery time windows that reflect the individual delivery needs of different customers, companies will be able to more accurately identify opportunities for improving their product delivery services. Therefore, manufacturing companies should begin collecting and recording data on the delivery time sensitivities of their customers and implementing this into their delivery performance measurement systems.

The appropriate delivery time windows can be collected at different levels. A general delivery time window can be defined for each different customer segment that exists and then be applied to all customers within this segment. Alternatively, it can be defined for individual customers. Cases may also occur where the appropriate delivery time window varies from order to order, even for the same customer. Therefore, in the most extreme case, the delivery window can be defined for individual order lines. Collecting data at this level would enable companies to more precisely manage their product delivery services. However, the process of collecting and recording this data may be resource intensive. Therefore, decisions should be made regarding where these resources are best allocated. For example, the appropriate delivery time window for the individual orders of the most important and most profitable customers can be recorded. The data can then be recorded at the individual customer level for medium-sized customers. Finally, the customers of a smaller size would simply be recorded as using the delivery time window most appropriate for the customer segment in which they belong.

Table 5.14 - Levels of delivery time window collection depending on customer type

Customer type	**Delivery time window data collection level**
Largest and most profitable customers	Order-line level
Medium-sized customers	Individual customer level
Smaller customers	Customer segment level

The case study further illustrated that a significant gap existed been the SC-OTD and CP-OTD across various delivery time windows and customer groups. These gaps represent opportunities for increasing customer satisfaction by improving the CP-OTD, which were not visible prior to quantifying CP-OTD. Additionally, by collecting and analysing customer-requested, supplier-confirmed and shipment dates and analysing this according to customer group contingencies, companies can identify current practices that lead to the dissatisfaction of customers. For example, patterns of orders being shipped earlier than promised to customers that did not tolerate early deliveries were recognised. Furthermore, a pattern was discovered of the company attempting to ship orders close to the initially requested shipping date, even after the order was confirmed for a different date. This was done to satisfy the needs of customers, but for specific groups of customers, this procedure could potentially increase dissatisfaction. These insights can help companies modify and improve their product delivery services to better serve the needs of individual customers. However, efforts to increase customer satisfaction may require heavy resource investments and the benefits gained as a result of the increase in customer satisfaction may be not outweigh these investments. Nevertheless, by identifying where specifically these opportunities are located, companies can conduct further analyses to determine which investments into increasing customer satisfaction are worth their cost.

6 Discussion

This section discusses the findings of the thesis in relation to the challenges of managing product and product-related service variety while minimising the negative impacts on the future business of existing customers.

6.1 Managing and reducing product variety while protecting the future business of existing customers

In response to RQ1, Study A and B explored existing methods for product variety reduction and found that they fail to address the issue of minimising the potential negative impacts that reduced product variety has on the ability of companies to satisfy the needs of their existing customers. Based on this gap in literature, the studies precisely defined the concept of linked revenue and, based on an existing procedure for product variety reduction by Hvam et al. (2019), developed a new procedure that include considerations of linked revenue. The procedure was tested in two cases studies conducted in manufacturing companies operating in different industries and of varying size. Both cases showed that the procedure led to great reductions in product variety, while at the same time preventing the termination of products with linked revenue, thereby avoiding related losses of customer business. In both cases, the reduction in product variety led to significant economic gains in the shape of released production capacity.

Study A and B contribute to the existing literature on the management and reduction of product variety (Closs et al. 2008; Escobar-Saldívar et al. 2008; Haug et al. 2013; Hvam et al. 2019; Myrodia and Hvam 2014) by proposing a new method to identify unprofitable products for termination while minimising the resulting loss of business from profitable customers. The proposed procedure is a step-by-step guide that is generic enough to be applicable in most manufacturing companies. Furthermore, it is designed to only require data that already exists and is readily available within the IT systems of manufacturing companies. Additionally, the procedure requires only limited product and market knowledge. These factors make the procedure simple and fast to implement. Furthermore, having a systematic evaluation of individual product variants to determine which to terminate and which to keep in the product portfolio simplifies the implementation process of the procedure. This is achieved by evaluating individual product variants based on turnover and contribution martin ratio. The logic being that the higher the turnover of a product is, the larger its potential is for becoming profitable through sales price increases or cost reductions and thus, a smaller CMR is acceptable. This analysis also results in the identification of products with high potential profitability based upon which initiatives can be launched to either increase sales prices or reduce production costs.

The usefulness of the procedure is illustrated by the results of the case studies. Despite the significant differences of the case companies, the expected economic gains achieved by the production capacity released due to longer producing the terminated products, was on significant size and considerably similar (see Table 4.8). Furthermore, semi-structured interviews with key stakeholders in each company confirmed the feasibility and usefulness of the procedure. It was viewed as being relatively problem-free and fast to implement. It was also recognised as being a useful tool for highlighting and communicating the rationale behind the decisions to terminate or protect individual product variants. Finally, stakeholders in the second case company plan to implement the procedure as a returning annual process, due to the significant value to be gained and the ease of conducting the analyses.

The case studies demonstrate the relevance of considering linked revenue in product variety reduction efforts. As illustrated in Figure 4.4 and Figure 4.5, if the procedure had been carried out without considering linked revenue, then large fractions of the business of the most profitable customers would have been put at risk, due to the termination of products purchased by these customers. The management of the plastic company recognised the importance of prioritising the satisfaction of the most profitable customers to protect and grow the business of these customers. By considering linked revenue in product variety reduction decisions, this goal is addressed. The proposed procedure contains a step devoted to defining which specific customers whose linked revenue should be protected. This evaluation and identification of specific customers is important to ensure that the desired results are achieved.

The proposed procedure addresses the common issue of internal pushback on product variety reduction efforts stemming from sales departments. Sales personnel typically have no incentive to reduce product variety, as this limits the assortment of products that is offered to customers and because their success in typically measured by turnover that is generated. This was an issue that was experienced on several occasions at the plastic company. The proposed procedure is therefore designed to reduce this internal pushback by actively involving to affected customer account managers. The collection of feedback from customer account managers also serves to ensure that valuable reasons for protecting currently unprofitable products are collected.

Finally, when analysing which unprofitable products to terminate, various reasons for why to not terminate products should be considered (Wilson & Perumal, 2009). The proposed procedure therefore contains a step where reasons for protecting product variants from termination are identified and the affected product variants are identified.

6.2 Managing and reducing product-related service variety while protecting the future business of existing customers

The challenges related to ETO product development and sales processes are similar to those related to the creation of customer-specific product-related services. Configurators are widely used in ETO companies to address these challenges. Therefore, in response to RQ2, Study C explored existing approaches for the development and implementation of configurators and found that existing approaches do not address several distinct obstacles related to the management of product-related services. Based on this gap in literature, Study C develops a new approach for the development of configurators for product-related services, based on existing approaches. The approach was tested in a case study in the plastic company resulting in improvements related to increased service cost transparency, improved service pricing accuracy, increased opportunities for differentiation of services according to customer groups and more formalized and structured service specifications.

Study C contributes to the existing literature on configurator development (e.g. Forza & Salvador, 2006; Haug et al., 2012, 2019; Hvam et al., 2006, 2008a; Mueller et al., 2022) by proposing a novel approach for the developing and implementation of configurators that address the challenges related to the management of product-related services. The challenges are mainly related to the scoping, analysis and modelling phases of the configurator development process. The ways in which the approach addresses these challenges a discussed in the following sections.

Manufacturing companies usually have comprehensive and readily available overviews of their product portfolios. However, overviews of existing product-related services may not be as comprehensive or accessible. To address this challenge, the scoping step of the proposed approach includes a systematic analysis and mapping of existing product-related services. This is followed by an analysis to evaluate and identify the product-related services that would be most valuable to include in the scope of the configurator.

A distinct characteristic of product-related services is that the availability of individual variants is directly dependent on the attributes of the products which the service is related and to the attributes of the customer to whom the service is provided. In the proposed approach, this is addressed by the inclusion of a step during which individual product-related service variants are analysed with the purpose of defining how their availability should be limited by specific customer and product attributes. The results are then expressed as constraints to be used in the configurator. These constraints ensure that impossible and unwanted products-services-customers combinations are avoided. Furthermore, they free the users of the configurator from manually having to keep track of these limitations. Finally, these constraints can be used to manage the behaviour of sales personnel to meet strategic goals.

Another characteristic of product-related services is that the cost of producing and providing them varies significantly depending on the characteristics of the selected products and the target customer. This is addressed in the proposed approach by the inclusion of a step during which the cost drivers of each product-related service are identified. Customised cost models are then developed based on these cost drivers to accurately calculate the cost of individual service configurations. The importance of accurately calculating the cost of product-related services is illustrated in Table 5.2 and Table 5.3. Increasing the accuracy with which the costs of product-related services are calculated, reduces the risk of under-estimating costs and thereby committing to contracts that ultimately turn out to be unprofitable. Similarly, the increased service cost transparency reduces the risk of over-estimating costs and thereby demanding non-competitive prices from the market, leading to the potential loss of business.

The proposed approach modifies the conceptual modelling phase by extending existing analysis models with a separate view containing product-related services. This ensures that the modules, attributes, constraints and cost models for each product-related service are documented and available when programming the configurator in the selected software shell. It also simplifies the process of extended an existing configurator with additional product-related services.

A specific focus of this thesis was on the product delivery service, as this is the most fundamental product-related service offered by manufacturing companies. A common metric used to assess the success of product delivery is OTD performance. Depending on the comparison date that is used to evaluate the timeliness of orders, the nature of OTD changes. Using the supplier-confirmed delivery date results in SC-OTD while using the customer-requested delivery date results in CP-OTD (Andersen, Hvam, & Forza, 2023). Both performance measures are useful and insightful, therefore, in response to RQ2, Study D systematically reviewed literature to synthesise how OTD was defined (regarding the use of different comparison dates) with a subsequent focus on how CP-OTD has been used as a performance measure. The study found that the use of CP-OTD has only received limited attention in literature. To fill this gap, Study D conducted a case study in the plastic company based on sales order lines from a 12-month period. The purpose was to explore how enhancing delivery performance measurement systems with CP-OTD, and customer-appropriate delivery time windows can enable companies to better manage product delivery services and to more accurately identify areas of potential improvement. Various insights were discovered and are discussed in the following sections.

Study D contributes to the literature on product delivery performance measurement by conducting a systematic literature review on the definition and use of OTD, with a specific focus on the use of different comparison dates. The literature found that most relevant articles do not specifically state which comparison date that is used in the research described. The lack of this information created obstacles to accurately interpreting, comparing and replicating studies. The literature review also revealed that among the articles that did specify the type of comparison date that was used, only few used the customer-requested delivery date, and even fewer discussed or quantified OTD using both the customer-requested and supplier-confirmed delivery date. Only a single article was found that explores ways to exploit the potential of quantifying both CP-OTD and SC-OTD using the same set of order data (Knoblich et al., 2015). However, this study models a supply chain specific to the semi-conductor industry and the behaviour of the supplier is regulated by a pre-agreed contract between the supplier and the customer. Furthermore, it uses simulated data as opposed to real empirical order data.

With customer growing increasing heterogenous and demanding (Stäblein et al., 2011), companies most likely serve customers with differing delivery time sensitivities. Consequently, to accurately assess OTD, different delivery time windows should be defined to reflect the delivery needs of different customers. However, the literature review found that only few articles discussed this potential of using several delivery time windows and none of these explored the potential of doing so through analyses of empirical order-line level data.

A case study in the plastic company addressed the identified gaps in literature by quantifying OTD using real empirical order-line level data from a 12-month period to quantify OTD using both the customer-requested and the supplier-confirmed delivery date, as well as using several customer-appropriate delivery time windows. The results showed that OTD performance varies significantly depending on selected comparison date type and delivery time window, meaning that based on the same set of data, different OTD performances can be obtained depending on the choice of comparison date and delivery time window.

It was found that by defining and using customer-appropriate delivery time windows to quantify the OTD of heterogeneous groups of customers, companies can increase the accuracy with which they asses their product delivery service performance. Significant benefits may therefore be gained through the analysis and collection of the delivery time sensitivities of customer groups. Collecting this data can be done at different levels of aggregations, i.e., at the level of individual order lines, at the level individual customers or at the level of individual customer segments. Defining delivery time windows at the level of individual order lines would result in the greatest OTD accuracy, however, collecting and recording data at this level may be time-consuming and resource intensive.

Alternatively, companies may collect and record this data at different aggregation levels depending on the size and importance of individual customers, such that OTD of the most important customers would be assessed at the highest accuracy, while lower levels of accuracy would be acceptable for less important customers.

The case study found significant gaps between SC-OTD and CP-OTD across various delivery time windows and customer groups. These gaps represent opportunities for increasing customer satisfaction by improving CP-OTD that were not visible prior to quantifying CP-OTD. Furthermore, by classifying order lines according to a joint comparison of the shipping date, the customer-requested date and the supplier-confirmed date and analysing the results using customer group contingencies, it is possible for companies to identify patterns in the product delivery service process that leads to the dissatisfaction of customers. These insights also present opportunities for increasing customer satisfaction through changes to processes and prioritisations. However, efforts to increase customer satisfaction may require heavy resource investments and the benefits gained as a result of the increase in customer satisfaction may be not outweigh these investments. However, enhancing delivery performance measurement systems with CP-OTD and customer-appropriate delivery time windows will enable companies to more accurately identify opportunities for improvement. Further analyses should then be conducted to determine which opportunities should be pursued.

7 Conclusion

This thesis presents ways for manufacturing companies to manage and reduce complexity while protecting the future business of existing customers. One conference article and three journal papers serve as the empirical body of the thesis. These studies address the formulated RQs by (1) developing and testing a procedure for product variety reduction that considers linked revenue, (2) developing and testing an approach for the development and implementation of configurators for product-related services and (3) conducting a systematic literature review on the use of CP-OTD followed by a case study to explore ways of enhancing delivery performance measurement systems to enable better management of product delivery services.

First, a procedure for product variety reduction that considers linked revenue was developed based on an existing method of product variety reduction (Hvam et al., 2019). The usefulness and feasibility of the proposed procedure was tested in two case studies. Both cases resulted in significant reductions in product variety, while preventing the termination of products with linked revenue, thereby avoiding related losses to the future business of customers. The reduction in product variety led to significant economic benefits in the shape of released production capacity. The studies illustrate that linked revenue is a concept that is highly important to consider in research investigating product variety reduction and in methods seeking to reduce product variety.

Next, an approach for the development and implementation of configurators for product-related services was developed based on existing approaches for configurator development. The proposed approach was tested in a case study in the plastic company. The approach addresses the distinct obstacles related to the management and configuration of product-related services and resulted in improved service cost transparency, improved service pricing accuracy, increased opportunities for differentiation of services according to customer groups and provided more formalized and structured service specifications.

Finally, a systematic literature review was conducted to synthesise how OTD is defined and used in literature. The literature study found that the use of CP-OTD received limited attention in literature. To fill this gap in literature, a case study was conducted in the plastic company. This case study found that by enhancing product delivery performance measurement systems with CP-OTD and customer-appropriate delivery time windows, companies can increase the accuracy with which they asses their product delivery service performance and thereby identify opportunities for better management of these services.

The intentional selection of a case company that experiences issues related to both product variety and product-related service variety, and who has a top-management team that prioritises the handling of these issues, supports the reliability of the findings and enriches literature on complexity management in manufacturing companies. The findings of the thesis have been presented at numerous lectures at the Department of Technology, Management and Economics and the Department of Engineering Design and Product Development and the Technical University of Denmark, at two academic conferences and at EIASM EDEN doctoral seminar. Furthermore, the relevance of the work has been met with positive feedback from other manufacturing companies.

7.1 Limitations and suggestions for future research

The work of this thesis focuses largely on the management of product variety and product-related service variety in the context of manufacturing companies. The selected main case company constituted an information-rich context to explore and test methods for the management of product and product-related service variety (Patton, 2015; Yin, 2018). The objectivity of the involved human actors and the rigour of the procedures applied were ensured by collecting data from multiple sources and by verifying the quality and validity of the data and the achieved resulted through sparing with managers in the plastic company and with follow researchers at the Technical University of Denmark. However, most findings of the thesis are drawn from single-case studies, which limits their statistical generalisability and calls for analytical generalisation.

The main study addressing RQ1 used a multiple-case study research approach. The feasibility and usefulness of the proposed procedure was tested in in the plastic company and in another Danish manufacturing company operating in the chemical industry. This strengthens the generalisability of the findings. The studies illustrated the relevance and importance of considering linked revenue in product variety reduction efforts. However, not all products have the same degree of linked revenue, as some products may not be important to the customer and those products can be terminated without risking the loss of this customer's business. Extensive expert knowledge of both products and customers is required to determine the degree of linked revenue in individual customer-product combinations. As the purpose of the proposed approach was for it to be relatively simple and quick to implement, it was decided to use a binary definition of linked revenue, meaning that if a product has ever been purchased by a customer whose linked revenue should be protected, then this product is protected from termination. However, modifying the approach to include a more elastic definition of linked revenue represent a potentially valuable direction for future research.

The two studies addressing RQ2 both use single-case study research conducted in the plastic company. Study C tests the usefulness of the approach for development and implementation of a configurator for product-related services. The approach only being tested in a single case study limits the generalisability of the findings. However, considering that the proposed approach provides guidelines that can easily be followed by other companies, it is expected that the benefits of this approach can be generalized. Companies selling physical products as their main offerings and also offering product-related services of a certain complexity are expected to achieve significant benefits from applying the proposed approach. Nevertheless, additional insights would be achieved by applying the proposed approach in additional case studies within other industries and with the inclusion of different product-relates services.

The final study also used a single-case study approach which limits the generalisability of the findings. However, due to the lack of fundamental understand of the topic that was explored and due to the difficulties associated with collecting and controlling the required data, an in-depth single-case study approach was preferred to using a broader, less in-depth multiple-case study approach (Shurrab et al., 2022). Furthermore, by presenting the results in the context of a single case study, the results were easier to comprehend for the reader. The study demonstrated that using appropriate delivery time windows at the aggregation level of individual order lines would further increase the accuracy of the OTD assessment. However, this information as not collected in the conducted case study. This potential is however worth exploring in future research.

7.2 Contributions to theory

Contributions to theory from this thesis include a deeper understanding of how to manage and reduce product and product-related service variety in manufacturing companies while protecting the future business of existing customers. Study B defines the concept of *linked revenue* and demonstrates its relevance in research that explores or provides methods for product variety reduction. Furthermore, a novel procedure for product variety reduction that considers linked revenue is presented. Study C contributes to existing literature on development and implementation of configurators by highlighting the distinct obstacles related to the management of product-related services. A novel approach is presented that addresses these obstacles. Finally, Study D presents a synthesis of existing literature on the definition and use of OTD with a specific focus on the use of different comparison date and the use of CP-OTD as a performance measure. Significant gaps were identified and explored through a case study, illustrating the valuable insights to be gained from using CP-OTD as a performance measure and the importance of defining appropriate delivery time windows to accurately assess the OTD performance of heterogenous groups of customers.

7.3 Contributions to practice

For manufacturing companies, this thesis provides insights and specific methods for effective management of product and product-related service variety that protect the future business of existing customers. A step-by-step procedure is presented for identifying unprofitable product variety that minimises the negative impact on the future business of existing customers. The procedure requires data commonly available in most manufacturing companies and only limited product and market knowledge, making it simple and quick to implement. Furthermore, a five-step approach for the development and implementation of configurators for product-related services is presented. This approach is applicable in any manufacturing company offering product-related services and can be used as a useful tool to manage the specification and pricing processes related to providing these services. Finally, insights are presented into how product delivery performance measurement systems can be enhanced with CP-OTD and customer-appropriate delivery time windows. The insights gained from this enhancement has the potential to improve the accuracy with which companies assess the OTD performance of heterogenous customers, thereby revealing valuable opportunities for more effective management of product delivery processes.

As this thesis was carried out in close collaboration with a company in which the methods were developed, this thesis can be argued as already demonstrating the significant value of the presented methods. Furthermore, the findings were presented and discussed as various lectures for master's and doctoral students at the Technical University of Denmark, at a Danish manufacturing network meeting at several other companies in Denmark with positive feedback regarding its relevance to other industries.

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Appendix

The papers referred to in the thesis are included in this section. A cover page stating relevant details of the manuscript and the submission status is included before each article.

Study A

Paper title	A product variety reduction procedure that considers linked revenue
Authors	Tobias Kondrup Andersen, Anders Haug, Lars Hvam
Paper type	Conference paper
Outlet	IEEM 2020 — IEEE International Conference on Industrial Engineering and Engineering Management
Paper status	Published

A procedure for product variety reduction that considers linked revenue

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Abstract – **Manufacturing companies are facing rising complexity due to customer demands for customized products and additional support services. This complexity comes at a high cost and the benefits to be gained from product variety reduction projects are therefore significant. Several methods for reduction of product complexity have been proposed in the literature. Such methods, however, to a large extent fail to consider the role of "linked revenue", i.e., the revenue from the sales of product variants that is lost if other product variants bought by the same customers are eliminated. To address this gap in the literature, this paper develops a method for product variety reduction that considers linked revenue.**

Keywords – **complexity management, linked revenue, product portfolio optimization, product variety reduction**

I. INTRODUCTION

Manufacturing companies are facing increasing demands from customers requiring customized products and additional support services [1]**.** Such demands lead to rising product complexity, which is often associated with significant costs [2]. As much of the created product variety is often not profitable [3, 4], many companies turn their focus towards product variety rationalization projects [5].

In the literature, several methods for the reduction of product complexity have been proposed [6]. These, for example, involve organizing products into A, B and C categories based on their turnover and contribution margin, whereafter initiatives to prune unprofitable C products are determined [6]. Such methods, however, to a large extent fail to consider the role of "linked revenue", i.e., the revenue from the sales of product variants that is lost if other product variants bought by the same customers are eliminated.

To address the gap in the literature, described above, this paper develops a method for product variety reduction that incorporates "linked revenue." The proposed procedure is tested at a manufacturing company, and the results support the usefulness of the procedure.

The remainder of the paper is organized as follows. First, relevant literature is briefly presented. Next, a procedure for product variety reduction that considers linked revenue is developed. Hereafter the procedure is tested at a manufacturing firm. Finally, the findings are discussed, and conclusions are drawn.

II. LITERATURE REVIEW

The notion of "complexity management" refers to the tasks of identifying and reducing complexity in an organization, which may concern products, business processes, and organizational structures, as well as the relationships between such areas [7]. There are many reasons for why companies are facing increased complexity, such as more diverse markets and consumer groups, and an increased number of product variants, components, subassemblies, production sites, suppliers, distribution centers and customers [1]. The focus of this paper is "product complexity", which concerns the complexity produced by components, functions, and technologies, as well as the interfaces between them [8].

Reference [9] describes two central factors that can increase complexity: (1) the amount of and diversity of the features that are to be manufactured, assembled and tested, and (2) the number, types and efforts required of the tasks that produce these features. Thus, product architecture decisions are central to product complexity, as these are associated with both the complexity of product assortments and the performance of business processes [10].

In the literature, several approaches related to product variety management have been defined. This includes research that develops approaches to implement product architectures and reduce product complexity [8, 10, 11, 12, 13, 14]. Complexity management has also been addressed from a supply chain management perspective through the development of methods for analysing and controlling complexity [15, 16, 17, 18, 19].

To limit the extent of this paper, a point of departure is taken in a recent procedure for product variety reduction, namely the 5-step procedure developed by [6]. This procedure aims at reducing product complexity based on quantification of product complexity cost. The procedure's five steps are: (1) scope definition for products and processes to be included in analyses, (2) products grouping into A, B, and C classifications, (3) identification, and on this basis, quantification of the most significant complexity cost factors, (4) the identification of initiatives to reduce complexity costs, as well as quantification of potential cost savings, and (5) evaluation and prioritization of variety reduction initiatives.

III. A PROCEDURE FOR PRODUCT VARIETY REDUCTION THAT CONSIDERS LINKED REVENUE

To address the issue of including linked revenue in product variety reduction analyses, such a procedure is proposed in this section. The method is developed as an extension of the five-step method developed by [6]. It consists of the following seven steps, which are subsequently described.

1. Allocation of complexity costs
2. ABC analysis of products and customers
3. Identification of customers with linked revenue
4. Analysis of sales date
5. Development of pruning scenarios
6. Development communication tools
7. Analysis of feedback from account managers

A. Step 1: Allocation of complexity costs

The first step follows the initial steps described in the five-step method [6]**.** Specifically, here the most significant complexity cost factors are identified, quantified, and allocated to individual product variants and customers. For all products and customers, complexity costs are subtracted from the contribution margin resulting in the complexity adjusted contribution margin (CM2).

B. Step 2: ABC analysis of products and customers

In this step, product variants and customers are organized into A, B and C categories according to a double Pareto analysis using both turnover (TO) and CM2. This means that each product and customer is given two A, B, or C categories according to their TO and CM2, respectively. The products and customers in the A category contribute to around 80% of the TO and CM2, the B products and customers contribute the next 15%, and the C products and customer contribute to the remaining 5% [6]. Some products and customers will be given two different categories. In these cases, the final rating given should be the lowest. For example, if a product is given a B for its turnover and a C for its contribution margin, the final category will be C.

C. Step 3: Identification of customers with linked revenue

In the third step, customer groups are analyzed to decide which of these are prone to linked revenue. For example, one customer segment may require that all their needs can be met by a single supplier, whereas another segment is mainly cost-driven and willing to use several suppliers to minimize costs. The analysis in this step also includes the identification of strategic C customers (i.e., C customers that are expected to become key customers in the future) with linked revenue.

D. Step 4: Analysis of sales data

In the fourth step, historical sales data are analyzed to identify C products that have never been purchased by A or B customers with linked revenue or by the strategic C customers identified in the previous step. Furthermore, an analysis is made to identify products that for reasons other than linked revenue should not be pruned. An example could be new products that have yet to mature in the market or products that are used as components in assembly products. The result of this step is a list of C products that can be pruned safely without risking the linked revenue of the most profitable customers. The remaining C products with linked revenue require further analysis before deciding to prune them.

E. Step 5: Development of pruning scenarios

In the fifth step, possible scenarios for pruning are developed. In this context, products with high TO but low CM2 have the potential to become profitable through price negotiations or cost reductions – while products with low TO will most likely never become able to cover their own fixed costs. Therefore, each of the C products identified as candidates for pruning in the previous step are evaluated based on their TO and contribution margin ratio (CM2R). The higher the TO of a product, the lower a CM2R can be accepted as a reason to keep it in the portfolio. For each scenario, the expected impacts are quantified and used as basis for the final selection of which scenario to initiate.

F. Step 6: Development of communication tools

In the sixth step, tools are developed to collect feedback from relevant account managers regarding the products marked for pruning. Comprehensive, but easily readable, overviews of which customers purchase each of these products are created for each account manager individually. Account managers are then asked to identify products that they do not believe should be pruned and to provide detailed reasons for such beliefs.

G. Step 7: Analysis of feedback from account managers

In the final step, feedback from the account managers is analyzed. Based on this feedback, a project steering committee can make the final decision of which products to prune and initiate projects for price negotiations or cost reduction for the remaining unprofitable products.

IV. METHODOLOGY

To investigate the proposed framework, a case study was carried out**.** Reference [20] defines a case study as “a study that investigates a contemporary phenomenon (the ‘case’) in depth and in its real-world context, especially when the boundaries between phenomenon and context may not be clearly evident.” Given that the purpose of this paper is to test a novel procedure for the reduction of product variety while considering linked revenue, the case study approach seems particularly suited. Specifically, rich data are needed to understand the strengths and limitations of the proposed procedure.

The company selected for the case study in this research is a European manufacturer of plastic components. The company has 200 employees and a yearly turnover of approximately 23 million Euros. The product variety in the company had increased rapidly and the need for product variety reductions had become apparent. The company was in a situation where a relatively small fraction of its customers made up the majority of turnover.

The data collection was performed in 2019 and 2020 using the ERP system of the company. All sales orders were extracted from a 24-month period from January 1, 2018 to December 31, 2019. These sales orders include 1,600 product variants and 1,260 customers. Furthermore, several interviews with key members of the case company were conducted, recorded, and analyzed. A total of 13 interviews were conducted spanning a total of approximately 28 hours. Table 1 contains information regarding interviewees, information type and interview time. All data were collected over a 12-months period in the case company.

TABLE I
INTERVIEWS

Interviewee	Information type	Interview time [hours]
Chief Operations Officer	Cost data	1 + 2
Operational Application Lead	Cost, customer & sales order data	3 + 2 + 4
Global Head of Supply Chain	Cost data	3 + 1
Global Product Manager	Customer data	3
Financial and Operational Controller	Cost data	2 + 2
VP of Marketing and Product Development	Customer data	1 + 3 + 1

V. RESULTS

This section describes the application of the proposed method in the case company.

In the first step, the most significant complexity cost factors were identified, quantified, and allocated to products and customers. The cost factors were internal freight, sales order handling and quality control. Complexity costs were subtracted from the contribution margin of each product and customer to calculate the CM2.

In the second step, products and customers were split into A, B and C categories. For products, the results showed that 343 could be characterized as A, 355 as B and 902 as C. For customers, the results showed that 65 could be characterized as A, 168 as B and 1027 as C. The relatively low number of A customers emphasizes the importance of considering linked revenue in product variety reductions, as the consequences of losing the revenue from these vital customers would be substantial. These results are summarized in Table 2.

TABLE 2
RESULT OF ABC ANALYSIS

	No. of products	No. of customers
A	343 (21%)	65 (5%)
B	355 (22%)	168 (13%)
C	902 (56%)	1027 (82%)

In the third step, the customer segments of the case company were analyzed. Through discussions with multiple departments it was concluded that customers in segments providing detailed long-term forecasts were expected to have a high degree of linked revenue, whereas spot-order customers were mainly cost-driven and not expected to have linked revenue. Furthermore, a list of strategic C customers with linked revenue was created.

In the fourth step, an extract was made of all sales orders from the last 24 months. Based in this dataset, a list was made of C products that have never been purchased by A or B customers with linked revenue or by any of the strategic C customers identified in the previous step. Then, all products launched within the last 24 months were excluded from the list of C products. Additionally, products used as components in A or B products or in C products with linked revenue were excluded from the list. The result of this process was a list of 424 C products that could be pruned without the risk of losing linked revenue from profitable customers. This corresponded to 47% of the total number of C products.

In the fifth step, four possible pruning scenarios were developed regarding the 424 C products identified in the previous step. Specifically, these products were split into five groups according to their annual TO. Based on this, scenarios were developed by using different minimum CM2R-values for products to be kept in the portfolio. Table 3 shows an example of two such scenarios. In this example, products with a TO above 7500 are never pruned, whereas products with a TO between 2500 and 5000 are pruned if they have a CM2R of less than 10% or 20% in scenario 1 and 2 respectively. Furthermore, products with a TO of more than 7500 will never be pruned, while products with a TO of below 500 will be pruned regardless of their CM2R.

The impacts of the scenarios were quantified by calculating the average CM2 earned per hour of production for the C products to be pruned and the average CM2 earned per hour for A products.

TABLE 3
EXAMPLE OF PRUNING SCENARIOS

	Minimum CM2R to keep products in portfolio	
TO/year	Scenario 1	Scenario 2
7500+	Never prune	Never prune
2500 - 5000	10%	20%
1000 - 2500	20%	30%
500 - 1000	40%	50%
0 - 500	Always prune	Always prune

If the case company can produce and sell these A products in the place of the pruned C products, it would result in an increase in the total CM2 of the company of between 0.6% and 1.8% depending on the chosen scenario. Additionally, the case company would save between 0.2% and 0.4% of its total inventory costs. Based on these data, the project steering committee agreed to recommend a scenario of pruning a total of 259 products.

In the sixth step, sales order data was used to create overviews of which customers purchase each of the products marked for pruning. This data was used to create individual overviews of the relevant products for each account manager. The account managers received the overviews and were asked to identify any products that they did not believe should be pruned and to provide a detailed reason for this belief. At the present time, not all feedback has been received from the account managers.

In the final step, feedback from account managers was collected and analyzed. Each product that the account managers had reasons for not wanting to prune were evaluated individually by the project steering committee. As feedback has not yet been received from all account managers, the list of products to be pruned is not finalized. However, the phasing out process has been initiated for the products for which feedback has been received.

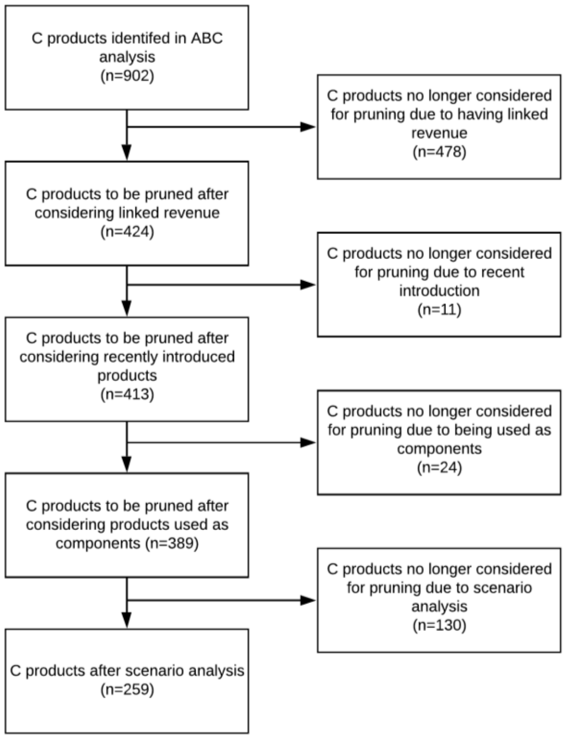

Fig. 1. Process of selecting C products to be pruned

VI. DISCUSSION

In step one, the case company identified 902 C products. In step three, 424 of these products were found to not have linked revenue. An additional 35 products were removed from consideration due to being used as components or having recently been introduced. In step five, the project steering committee recommended the implementation of a scenario that prunes a total of 259 products. The result of the process is summarized in fig. 1 where the 902 C products are reduced to 259 products to be pruned. The case study demonstrates the relevance of considering linked revenue. Specifically, if this pruning method had been applied without the steps that consider linked revenue, 546 products would have recommended for pruning instead of the 259 products identified by using the current procedure. The remaining 287 products are purchased by customers defined to have significant linked revenue and among these customers are several of the very largest. The total turnover of these customers makes up 69% of the total turnover in the company.

If the concept of linked revenue had not been considered in the product variety reduction project, all this turnover would be at risk. On the other hand, the remaining 259 products to be pruned are bought by customers contributing to only 16% of the total turnover. This is illustrated in fig. 2. (the exact number of customers is not disclosed due to confidentiality). Thus, the case study illustrates the importance of considering linked revenue in product variety reductions.

The final steps of the procedure about collecting and analyzing feedback from the responsible account manag-

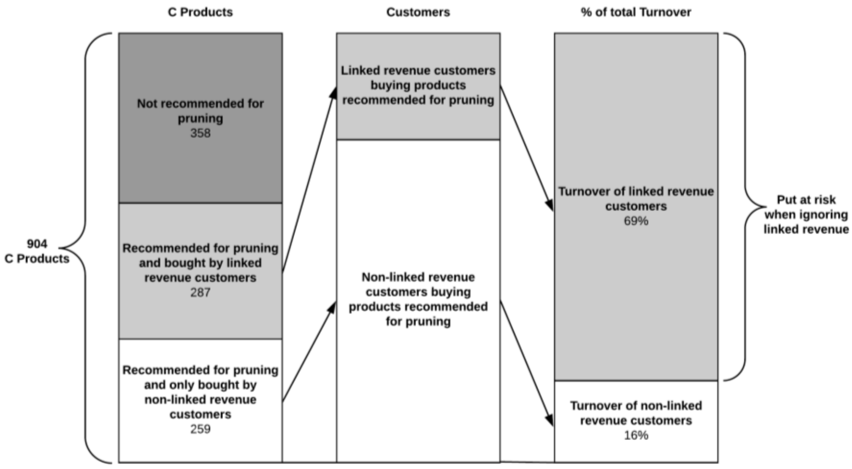

Fig. 2. Linking revenue to products and customers

ers is designed to help ensure that products are not blindly pruned without consulting the sales departments. Additionally, by including members of the sales department in the pruning process, the potential pushback is reduced significantly. The method can be used to easily identify unprofitable products that can be safely pruned without risking the business of vital customers.

This proposed procedure focuses only on identifying products with linked revenue. However, this should not be understood such as if a product has ever been bought by a linked revenue customer, no matter the quantity, it should be protected from pruning. Rather, the method should be extended to analyze the strength of the linked revenue between products and customers. For example, a product that is only purchased in small quantities at low frequency might be rated as having only limited linked revenue. Products like these should be required to have better performance than products with no linked revenue before being protected from pruning. This discussion is, however, outside the scope of the paper.

VII. CONCLUSION

This paper addressed the issue that existing methods for reduction of product complexity to a large extent fail to consider the role of “linked revenue.” To address this gap in the literature, this paper developed a method for product variety reduction that incorporates “linked revenue.” The application of the procedure in a manufacturing company indicated the usefulness of the procedure. Specifically, the method (1) identifies unprofitable products that can be safely pruned without risking the revenue of vital customers, (2) systematically evaluates the profitability and potential of these products to decide which to prune, and (3) collects feedback from the affected account managers. Thus, the procedure ensures that products are not blindly pruned, while also reducing pushback on the product variety reduction project from the sales department.

As a single case study approach does not allow for statistical generalization, instead analytical generalization may be applied [20]. Specifically, given the typicality of the manufacturing firm studied regarding organization, product variety and similar, the findings seem likely to be applicable in a high number of firms with similar characteristics. As this type of generalization is associated with some uncertainty, future research to further study the application of the proposed procedure is recommended.

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Study B

Paper title	The role of linked revenue in product variety reduction: A procedure and two case studies
Authors	Tobias Kondrup Andersen, Mads Lunde Andersson, Lars Hvam, Anders Haug
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The role of linked revenue in product variety reduction: A procedure and two case studies

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The role of linked revenue in product variety reduction: A procedure and two case studies

Modern customers require a wide range of customised products, priced low and delivered on time. Such demands are increasing complexity costs in manufacturing companies, leading them to pursue product variety reduction projects. Approaches for managing and reducing product variety have been proposed in the literature; however, these approaches fail to consider the importance of minimising the loss of business from profitable customers as a result of the reduced product portfolio. On those grounds, this article proposes a procedure for product variety reduction that (1) identifies products that are unprofitable and that can be terminated without impacting the company's business with the most profitable customers, (2) evaluates the potential profitability of these products and (3) reduces internal pushback on the termination of products by involving affected customer account managers. The procedure was tested at two manufacturing companies: the results support the usefulness of the procedure.

Keywords: complexity management; linked revenue; product portfolio optimisation; product variety reduction; SKU reduction; SKU rationalization

Introduction

Today, manufacturing companies are experiencing increasing demands from customers for customised products and supporting services (Jacobs and Swink 2011; Stäblein et al. 2011), which is prompting these businesses to broaden their product portfolios, a strategy often associated with increased costs and diminished performance (Gilbert et al. 2007; Mariotti 2008; Myrodia et al. 2021; Trattner et al. 2019; Wilson and Perumal 2009). Much of this product variety ultimately becomes unprofitable (Rigby 2017; Thiel et al. 2017); for this reason, many companies have turned their focus to reducing product complexity (Bannasch and Bouché 2016).

Several methods for identifying and reducing non-value adding product variety have been proposed (e.g. Escobar-Saldívar et al. 2008; Hvam et al. 2019; Myrodia and Hvam 2014; Staśkiewicz et al. 2022). However, these approaches largely fail to provide solutions that consider how to minimise the negative impact of the reduced product variety offered to customers, which in some cases may include lost revenue if the impact manifests in a customer's decision to do business with other suppliers. We term this phenomenon *linked revenue*, i.e., the revenue that is lost due to a decrease in the amount of product variants sold when customers who previously purchased those products no longer do so after other product variants purchased by the same customer are terminated. Given the lack of product variety reduction procedures that consider this concept, the present study develops such a procedure. The usefulness of the procedure was tested in two industrial case studies.

This paper is structured as follows. First, relevant literature is reviewed, and the findings highlighted are used to shape a procedure that considers linked revenue. Next, the research method is described, after which each of the two case studies is presented and analysed, and the two cases are compared and discussed. The paper ends with conclusions drawn from these analyses.

Literature review

Complexity management involves identifying and reducing complexity in organisations within products, processes and organisational structures (Wilson and Perumal 2009). Manufacturing companies are experiencing increasing complexity for a variety of reasons, including globalisation (Lee 1996; Ulrich 2006), mass customisation (Pine, Joseph, and Victor 1993), increasingly demanding and heterogenous customers (Jacobs and Swink 2011), distribution channel expansions (Bilgen and Günther 2010) and the introduction of new brands, functionalities and packaging types adapted to meet customers' individual needs (Brun and Pero 2012).

Increasing complexity is recognised by top managers as a major challenge faced by companies today (IBM 2010; Kearney 2009). Thus, many manufacturing companies prioritise product variety reductions (Bannasch and Bouché 2016). Complexity management strategies from a supply chain management perspective have been researched extensively by developing methods for analysing and controlling complexity in the supply chain context (Bozarth et al. 2009; Choi and Krause 2006; Closs et al. 2008; ElMaraghy et al. 2013; Forza and Salvador 2008; Haug 2013; Lyons et al. 2020; Wan et al. 2012; Wu et al. 2007). Furthermore, studies have explored approaches to implementing product architectures and to reducing product complexity (Haug 2013; Lindemann et al. 2010; Meyer and Lehnerd 2011; Mortensen et al. 2010; Yang et al. 2008; Zheng et al. 2018).

Consequently, several methods for identifying and reducing non-value adding product variety have been proposed (Escobar-Saldívar et al. 2008; Hvam et al. 2019; Myrodia and Hvam 2014; Staśkiewicz et al. 2022). Hvam et al. (2019) suggested a systematic and general five-step procedure that (1) defines the scope of the analysis, (2) conducts an ABC (A, B and C categorisation) analysis of individual product variants according to their turnover and contribution margin, (3) identifies and quantifies significant complexity cost factors, (4) identifies and quantifies initiatives for the reduction of complexity costs and (5) evaluates and prioritises those initiatives. However, these methods, to a considerable extent, fail to address the importance of minimising the loss of business from customers resulting from the terminations in product variety. More specifically, the descriptions of a few methods touch on the issue, but they do not provide the details necessary to understand ways to address it. Myrodia and Hvam (2014) expressed concern about this gap in the literature, and they briefly highlighted the usefulness of considering linked revenue when conducting product variety rationalisation projects. Nevertheless, in their subsequent case study, the impact of linked revenue was not considered. Similarly, Flapper et al. (2010) developed a conceptual model to identify the optimal product assortment based on the assumption that customers will only place orders if all their desired products can be delivered on time. This approach, while interesting, does not provide companies with an easy-to-follow procedure for identifying and reducing unprofitable product variety while minimising the turnover lost from profitable customers.

The product variety reduction procedure that considers linked revenue proposed in this paper is based on the procedure developed by Hvam et al. (2019), given its general applicability and level of detail, as well as the positive results of its empirical testing. The purpose of the proposed procedure is (1) to identify unprofitable product variants that can be terminated without risking the loss of business from the most profitable customers, (2) to systematically evaluate the potential profitability of these products and (3) to reduce internal pushback on product terminations by collecting feedback from affected customer account managers. This procedure is described in more detail in Section 3.

Method for product variety reduction that considers linked revenue

As noted, the product variety reduction procedure proposed that considers linked revenue was founded on the procedure suggested by Hvam et al. (2019). Similar to the purpose of that procedure, the procedure outlined herein is intended to serve as a generic, step-by-step guide that manufacturing companies can follow to identify and systematically evaluate unprofitable product variety and to assess the impact of terminating this variety. Moreover, our procedure is modified to also minimise the negative impact that the termination of product variety may have on business from the most profitable customers. Furthermore, stakeholders of departments typically responsible for internal resistance to product variety reductions are directly incorporated into the procedure as a strategy to reduce that resistance. Finally, the procedure is designed so that only data readily available in the enterprise resource planning (ERP) systems of most companies is required, while extensive product or market knowledge is not necessary for its implementation.

However, extensive expert knowledge of both products and customers is required to determine the degree of individual customers' *linked revenue*, a concept central in the proposed procedure to which we apply a binary definition. Specifically, if a product has ever been purchased by one of the most profitable customers, then it is considered to have linked revenue and is protected from termination. However, not all products have the same degree of linked revenue, as some products may not be important to the customer: those products can be terminated without risking the loss of this customer's business. If the knowledge needed to make these determinations is available, the method can be extended to consider these factors. Nevertheless, the overall purpose of this method is to explain how to conduct a relatively simple and quick product variety reduction project that only requires data that most manufacturing companies already have available as extracts from their ERP systems. The procedure only aims to identify *the lowest hanging fruits*. In other words, it should be used by companies to gain experience in the process of conducting product variety reduction projects that may enable additional, more complex product variety reduction tasks, such as by using a more elastic definition of *linked revenue* or by considering product substitutability and product need overlap.

Step 1: ABC analysis of product variants and customers

Step one is to conduct an ABC analysis of product variants and customers. First, the products to include in the analysis must be selected. The products should be comparable, meaning that the ways in which they are manufactured and handled by the company should be adequately similar (Hvam et al. 2019). The aggregation level on which to base the customer evaluation must also be decided. In this context, businesses might serve customers from the same company who are located in different countries or regions. Thus, the next decision is whether to consider these customers separately or as a single entity when conducting the ABC analysis. If they are considered as separate entities, they may be rated with different ABC categories. This means that if the customer in one country is rated as a C-customer and the customer in another country is rated as an A-customer, then only the revenue of the second customer will be considered as linked revenue. If this condition is not acceptable, then the turnover and contribution margin of these two customer entities should be combined, and the ABC categorisation should be done based on this sum.

The ABC analysis should be based on sales data from an appropriate period. At least one year’s worth of sales data should be used to account for seasonality. Moreover, using data from a longer period reduces the risk of missing the linked revenue of products that are purchased infrequently. At the same time, it introduces the risk of changes in the purchasing behaviours of customers.

Similar to the procedure proposed by Hvam et al. (2019), the procedure described herein calls for double ABC analyses of the product variants and customers in scope to divide them into categories based on their turnover and contribution margins. Each product variant and customer is classified into two categories, one based on turnover and one based on contribution margin. The products and customers responsible for the top 80% of turnover and contribution margin are categorised as A-products/customers, while those responsible for the next 15% are B-products/customers and those responsible for the final 5% are C-products/customers. If a product variant or customer is given two different ratings, the final rating will be the lowest of the two. For example, if a product variant is categorised as an A-product due to its turnover but as a B-product for its contribution margin, then the final categorisation will be as a B-product.

If analyses have been conducted in the company to allocate complexity costs to individual product variants and customers, then these costs should be subtracted from the contribution margin, and the resulting value should be used in the ABC analysis. However, if such cost allocation analyses have not been conducted, the traditional contribution margin values should be used.

The outcome of this step is a list of C-products to be analysed and further evaluated for termination, as well as a list of all customers categorised as either A, B or C.

Step 2: Identification of relevant customers

The purpose of step two is to identify groups of customers that are prone to linked revenue and to define which customers represent an important enough part of the company’s business to be associated with significant linked revenue. In this context, many companies serve several customer segments, and customers in one segment may prioritise having their entire needs met by a single supplier, while customers in another segment may be more cost sensitive and, hence, more willing to engage with multiple suppliers of similar products to obtain the lowest price possible. In this example, the first customer segment would be more prone to linked revenue than the second. At this point, the market segments of the case company should be analysed to identify customer segments with high and low degrees of linked revenue.

The next task is to decide which buyers to consider vital customers so the protection of their linked revenue can be prioritised. The business of A-customers should always be protected, but the business of C-customers should not be, while the decision on whether to prioritise the protection of a B-customer's business depends on the situation of the company in question; for example, if only a few, very large A-customers exist, only protecting their linked revenue would be risky. Additionally, strategic customers should be identified: these are customers that are not currently performing well but are expected to become profitable in the future. The linked revenue of these customers should also be protected.

The outcome of this step is a list of customers that are considered to have significant linked revenue.

Step 3: Analysis of sales data for linked revenue

In Step 3, sales order data are extracted from the company for the period defined in Step 1. These data should contain information on product variants, customers, turnover and contribution margin. The sales order data are analysed to identify C-products that have never been purchased by any of the customers whose linked revenue was deemed worthy of protection in Step 2. The outcome is a list of C-products that, if removed from the portfolio, do not put the linked revenue of the most profitable customers at risk. These products are further evaluated for termination in the following steps.

Step 4: Identification of product variants to be protected from termination

When identifying unprofitable product variety to terminate, reasons for keeping these product variants in the portfolio must also be considered, in addition to considering reasons to terminate the product (Wilson and Perumal 2009). Therefore, the purpose of this step is to identify products that should be protected from termination despite their poor financial performance at the time of the assessment. Following are some product variants that may need to be protected from termination:

- Products that have only recently been launched that need time to reach their sales potential in the market (while the time required to reach that potential varies across different types of products and, therefore, should be evaluated by the company)
- Products that the company is obligated by contract to offer to certain customers
- Products without which the product range within a certain product family may appear incomplete
- Products that are both being sold as finished products and being used as components in other, more profitable products
- Products within certain product ranges that are currently unprofitable because they are produced using new and expensive production technologies but may become profitable in the future if the technology improves and becomes cost efficient
- Byproducts derived from chemical side reactions of manufacturing processes that are not considered waste and the products derived from the primary/main production output, the termination of which would not lead to significant process simplifications or complexity reductions

The outcome of this step is a list of products that should be protected from termination despite currently demonstrating poor financial performance.

Step 5: Development of termination scenarios

In Step 1, when products were categorised according to a double ABC analysis using both turnover and contribution margin and a product received different ratings based on the two factors, the lowest value was selected as the final rating, as explained previously. This means a product could receive a C-rating if it had a low contribution margin while having a turnover large enough to merit an A-rating. Products rated in this way are being purchased by customers on a large scale and therefore represent a larger potential in the market compared to products that receive a C-rating for both turnover and contribution. Consequently, if the sales price is too low or the production costs are too high for the product to be profitable, such products should not blindly be terminated because they can be converted from poor performers to profitable items by increasing the sales price or reducing production costs. Therefore, scenarios are created that systematically evaluate each product variant according to its turnover and contribution margin ratio (CMR) to determine whether it should be nominated for termination.

To accomplish this, first, the product variants are divided into pools according to their total turnover. These pools should divide the product variants into groups that are homogenous enough to be evaluated according to the same criteria. Multiple scenarios are created with defined minimum contribution margin ratings required to qualify the products in each pool to be kept in the portfolio. Figure 1 illustrates the concept of evaluating product variants according to three scenarios. Here, Product X has such a low turnover that even with an adequate CMR, it will be terminated in all three scenarios. Product Y has a CMR similar to that of Product X but has a much higher turnover. Therefore, this product will not be terminated in any of the three scenarios. Lastly, Product Z has a relatively high turnover but a low contribution margin ratio. Consequently, it will only be terminated in Scenario 1, which is the most conservative scenario.

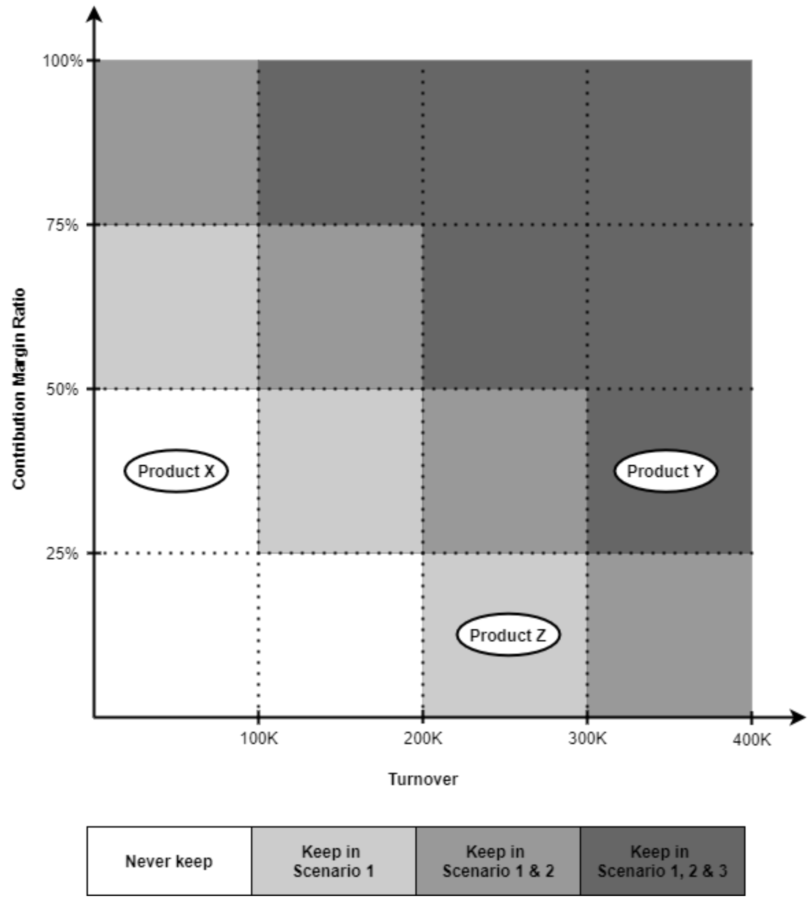

Figure 1 - Evaluation of product variants according to turnover and contribution margin ratio for three scenarios

The number of products to be terminated in each scenario is determined, and the impact of terminating these products is quantified. This is done by calculating the production capacity to be released by terminating these products from the company portfolio and then calculating the value to be gained by using this production capacity to manufacture and sell A-products instead. The impact of each scenario is presented to a steering committee, and a decision is made regarding which scenario with which to continue. The outcome of this step is a list of C-products that are nominated for termination, which are then further evaluated in the following steps.

Step 6: Collection of account manager feedback

The purpose of this step is to collect feedback from account managers on the products that were nominated for termination. Personalised overviews are created for each account manager outlining what their account customers have historically purchased from among the products nominated for termination. The volumes purchased and the prices charged are specified. The account managers are then asked to identify any products they believe should not be terminated from the company portfolio and to explain why the product should not be terminated. Products may be protected from termination at this stage because the manager is currently negotiating with A-customers on the sale of a large volume of this product or because the company is required by contract to offer this product in a specific period. A firm deadline for submitting feedback should be defined and communicated to the account managers.

The outcome of this step is a collection of arguments to support protecting specific products from termination.

Step 7: Analysis of feedback from account managers

The purpose of the last step is to make the final decision about which products to terminate. The feedback from account managers collected during the previous step is presented to and discussed by the project steering committee so decisions can be made regarding which products to terminate. Additionally, price negotiations or cost reduction projects can be initiated for the unprofitable products remaining in the product portfolio. The outcome of this step is the list of products to be terminated.

Methodology

To test the usefulness of the developed procedure, a multiple case study approach – an approach in which two or more cases investigate the same phenomenon (Yin 2018) – was followed. The case study approach was appropriate for this investigation because it involves in-depth studies of a phenomenon in its real-life context, which serves to inform a detailed understanding of the phenomenon in focus (Miller and Tsang 2011; Yin 2018) – in this case, the effects of implementing the proposed procedure. The multiple case study design, in particular, provides information about differences and similarities across cases (Yin 2018) that establishes a stronger basis on which to draw conclusions in the context of investigating the usefulness of a new procedure. Thus, two relatively different cases (in terms of size and product) that had carried out the proposed procedure were selected to investigate its applicability across different types of manufacturing companies. The characteristics of these two cases are described next.

Case context

The company selected for the first case study (Case A) was a Danish process manufacturing company operating in the plastics industry. The company employed approximately 200 staff and reported an annual turnover of 23 million euros. The company's product variety had been rapidly increasing, resulting in deteriorating financial and operational performance. The second case company (Case B) was a Danish process manufacturing company operating in the chemical industry. This company was staffed by approximately 2,100 employees and documented an annual turnover of 840 million euros. The company had invested heavily in research and development, resulting in the continual introduction of new products and technologies. With no procedures for product portfolio reduction in place, the innovation focus has resulted in a steady increase in the product mix, leading to operational and financial deficiencies. Both case studies were conducted in flow manufacturing companies with production facilities located in Denmark; however, the companies operated within different industries and differed significantly in size.

Data collection and analysis

For Case A, data collection spanned a nine-month period that started in 2019. Interviews were conducted with key employees in the case company to document the analysis process during the project. Additionally, follow-up interviews were conducted in 2022 to evaluate the impact and usefulness of the procedure. Table 1 describes the interviews that were conducted during Case Study A.

Table 1 - Interviews in Case Study A

Purpose	*Attendees*	*No. of interviews*
Collect and analyse cost data	Chief Operations Officer Global Application Lead Supply Chain Manager Financial and Operational Controller	*5 interviews* *(30–60 minutes each)*
Collect customer data	Global Application Lead Global Product Manager Vice President of Marketing	*3 interviews* *(30–45 minutes each)*
Collect, clean and analyse sales order data	Global Application Lead	*2 interviews* *(60 minutes each)*
Collect and analyse production process data	Chief Operations Officer Supply Chain Manager Financial and Operational Controller	*3 interviews* *(60–90 minutes each)*
Evaluate procedure	Customer Account Managers (3) Global Product Manager	*4 interviews* *(30 minutes each)*

For Case Study B, data were gathered between June and November 2022. Company A followed all seven steps of the proposed procedure, but the procedure was still ongoing at Company B, so only the first five steps were finished and documented for this case study. (At the writing of this article, Company B had yet to conduct the final two steps of the procedure.) Nevertheless, semi-structured interviews with key employees (i.e. two product line directors, one master data manager and one commercial finance director) were conducted to document the analysis process and to evaluate the usefulness of the procedure during the project. Table 2 describes the interviews conducted during Case Study B.

Table 2 - Interviews in Case Study B

Purpose	*Attendees*	*No. of interviews*
Collect and analyse cost data	Head of Finance BI & Master Data Finance Business Partner	*4 interviews* *(45–60 minutes each)*
Collect customer data	Head of Finance Business Intelligence & Master Data Finance Business Partner	*4 interviews* *(45–60 minutes each)*
Collect, clean and analyse sales order data	Head of Finance BI & Master Data Finance Business Partner	*4 interviews* *(45–60 minutes each)*
Collect and analyse production process data	Master Data Manager	*2 interviews* *(60 minutes each)*
Evaluate procedure	Master Data Manager Product Line Directors (2) Commercial Finance Director	*3 interviews* *(60 minutes each)*

The case data were collected in two phases. During the first phase, data were continuously collected as part of the projects. These data were used to understand the process for and effects of applying each of the steps of the proposed procedure. During the second phase, information was collected pertaining to overall experiences with and the overall impact of implementing the proposed procedure. In addition to gathering information through interviews, data were also obtained from documents containing cost, customer, sales order and production process records. Interview data were analysed using *open coding* to extract meaning.

Specifically, *open coding* involves segmenting data into meaningful expressions and describing them in a single word or short sequence of words, to which relevant annotations may be attached (Flick 2009). From this work, the case descriptions presented in the two subsequent sections emerged. Finally, the two cases were compared in terms of the effects of the product variety reduction projects and their application of the proposed procedure. In this context, to investigate the value of the proposed procedure in each case, analyses were conducted to explore the potential outcomes for scenarios in which linked revenue was not considered. This was done by quantifying the impact of following the procedure without protecting products that were purchased by customers with linked revenue, or in other words, skipping Step 3 (as described in Section 3.3).

Case Study A

Step 1: ABC analysis of product variants and customers

The main products sold by Company A were injection molded plastic parts. These products were manufactured and handled similarly, so they were appropriate for an analysis of all variants manufactured in-house. Product variants that were purchased from suppliers and then sold were not included in the scope of the analysis. Moreover, many customers were split into several individual customer accounts based on industry or geographic location. The company decided to aggregate these customer accounts into main customer chains and conduct the ABC analysis based on these chains. For this approach, the turnover and contribution margin values of a customer chain that consists of a small customer account in one region and another larger customer account in another region are summed, and this sum serves as the single ABC rating of the customer chain. Finally, sales data were used from a 24-month period, which resulted in more than 115,000 order lines covering 1,600 product variants purchased by 1,260 customers.

Previously, the company had conducted projects to allocate complexity costs to their individual product variants and customers. The complexity costs allocated included the costs of internal freight, sales order handling and quality control. Therefore, these costs were subtracted from the contribution margin of each product variant and customer, and the ABC analysis was based on this complexity cost adjusted contribution margin (CM2).

The ABC analysis was performed for product variants and customers. The distribution of ABC ratings as depicted in Table 3 illustrates that a relatively limited fraction of customers were categorised as A-customers (5%), which means that a small number of customers were responsible for the majority of the company’s business. This emphasises the importance of considering linked revenue, as losing the business of these customers would have a significant impact on the overall business of the case company.

Table 3 - Distribution of product variants and customers according to ABC categories in Case Study A

	No. of product variants	**No. of customers**
A	343 (21%)	65 (5%)
B	355 (22%)	168 (13%)
C	902 (56%)	1,027 (82%)

Step 2: Identification of relevant customers

The customers of the case company competed on different parameters. In this context, the case company served two main groups of customers. The first customer group provided long-term forecasts and heavily valued having most of their needs met by the same supplier. These customers were sensitive to linked revenue. The other customer group placed spot orders and were mainly cost driven. These customers were willing to use multiple suppliers of similar products to obtain the lowest price possible and were, therefore, less sensitive to linked revenue. As such, only customers in the first group were considered to be associated with linked revenue. The first customer group was responsible for approximately 70% of company turnover, while the second group was responsible for the remaining 30%.

Furthermore, both A- and B-customers were viewed as being associated with linked revenue, while several C-customers were identified as strategic customers, meaning that the company expected these customers to become key customers in the future. These customers were also defined as having linked revenue. On this basis, a list of customers for which linked revenue should be protected was produced.

Step 3: Analysis of sales data for linked revenue

In this step, all C-products that had never been purchased by customers associated with linked revenue were identified based on sales order line data from the specified 24-month period. This reduced the number of potential C-products from 902 to 424, meaning that 478 C-products were protected from termination due to having historically been purchased by customers associated with linked revenue. The remaining 424 C-products were further evaluated in the following steps.

Step 4: Identification of product variants to be protected from termination

Next, workshops were conducted to identify reasons to protect product variants from termination despite poor financial performance. Based on these sessions, product variants that had recently been launched and, therefore, had yet to reach their full market potential and product variants that were used as components in other, more profitable product variants were protected from termination.

Company A indicated that products required approximately two years to reach their full potential in the market. Therefore, all products that had been introduced less than two years before the last date of the data extract were protected from termination: 11 products were protected for this reason. Furthermore, several products in the company portfolio were both sold as finished products and used as components in other products. Products used as components in other products that were rated as A- or B-products or in C-products that were associated with linked revenue were also protected from termination: this resulted in the protection of 24 additional products. Thus, in this step (Step 4), 35 of the 424 C-products remaining after Step 3 were protected from termination, leaving 389 C-products to consider in Step 5.

Step 5: Development of termination scenarios

The remaining 389 C-products were divided into groups according to their turnover. Company managers engaged in discussions to determine a way to organise these groups so that the products in each could be comparably evaluated. The method of classification decided upon produced five groups.

Four scenarios were designed to evaluate which products should be nominated for termination, and a specific CMR minimum was established for each of the four scenarios for each group of products. The four scenarios required increasing CMR levels to keep products in the portfolio. If the products in any given group were assigned a CMR above the predetermined minimum in the scenario under consideration, then the product was kept in the portfolio. The scenarios are described in Table 4. For confidentiality reasons, the turnover and CMR values have been multiplied by a fixed factor.

Table 4 - Termination scenarios for Case Study A

Turnover per year	Minimum CMR for Scenario 1	Minimum CMR for Scenario 2	Minimum CMR for Scenario 3	Minimum CMR for Scenario 4
5,000+	Never terminate	Never terminate	Never terminate	Never terminate
5,000 – 2,500	10%	20%	30%	40%
2,500 – 1,000	20%	30%	50%	Always terminate
1,000 – 500	40%	50%	70%	Always terminate
500 – 0	Always terminate	Always terminate	Always terminate	Always terminate

After having identified the product variants to be nominated for termination according to each of the four scenarios, the expected impact of each scenario was quantified by calculating the number of production hours that would be released and the contribution margin that would be lost by terminating the identified C-products. The value of the released production hours was calculated by multiplying the number of production hours by the average contribution margin earned by A-products. Assuming that the released production capacity would be used to produce A-products and that these A-products would all be sold, the impact of the scenarios would be any increase in the annual CM2 between 0.63 and 1.84 percentage points. Table 5 shows the impact of each scenario.

Table 5 - Impact of termination scenarios in Case Study A

	No. of products nominated for termination	Percentage point increase in annual CM2
Scenario 1	238	0.63
Scenario 2	259	0.81
Scenario 3	331	1.39
Scenario 4	378	1.84

The expected impact of each scenario was presented at a steering committee meeting. Due to the high number of products to be terminated in scenario 3 and 4, the committee decided to follow a more cautious approach and continue with scenario 2, meaning that a total of 259 C-products were nominated for termination.

Step 6: Collection of account manager feedback

Overviews were created for the customers who had historically purchased any of the 259 products nominated for termination. Personalised overviews were then produced for each customer account manager in the company for all customers served by that manager. These overviews contained information on the customers that had purchased each product variant as well as the total turnover and contribution margin values for the products; the documents then were distributed to the customer account managers, who were asked to note the products that they did not believe should be terminated and to provide a detailed reason to support their position. They were given a two-month deadline to submit their feedback; however, this deadline was extended by an additional two months to ensure that all feedback was collected.

Step 7: Analysis of feedback from account managers

The feedback from account managers was organised and presented at a steering committee meeting. All product variants that the managers proposed keeping in the company portfolio were discussed. The reasons provided by the account managers were evaluated, and then a determination was made on whether each product should remain active or be removed from the product portfolio.

At the end of the project, 252 products were approved for termination. Six product variants were allowed to remain active because account managers reported that orders of a significant size were being discussed with customers. One product variant was allowed to remain active on the basis of reports that it was being used as a component in a more profitable product variant. Due to an error in product master data, this issue had been overlooked during Step 2 when identifying products to protect from termination. An analysis was launched to identify other products in similar situations, but none were identified.

Evaluation of usefulness and impact of the proposed procedure

During Case Study A, 902 C-products were identified and evaluated for termination. Of these, 478 were protected from termination due to the linked revenue of A- and B-customers. An additional 35 products were protected from termination because they had not yet reached their full market potential or because they were being used as components in other product variants. The potential profitability of the remaining termination candidates was systematically evaluated, and the expected impact of terminating these products was quantified according to four termination scenarios. Personalised overviews were considered by the affected customer account managers, who then provided feedback on termination recommendations, thus reducing internal pushback and resulting in an additional seven products being protected from termination. The procedure ultimately identified 252 products for termination, resulting in an expected increase to the annual CM2 of 0.79 percentage points.

Semi-structured interviews were conducted with three customer account managers and the global product manager to evaluate the feasibility and usefulness of the proposed procedure. They saw the procedure as being relatively simple to follow, as it only required currently available data and limited market knowledge. They viewed the procedure as a useful way to communicate the rationale for nominating unprofitable products for termination and the expected impact of doing so. This simplified the decision-making process and reduced internal pushback.

The customer account managers expressed appreciation for the way their input was collected and considered as an element of this procedure. The structured and targeted process for collecting feedback from account managers promoted their ability to provide specific feedback easily and efficiently.

Case Study B

Step 1: ABC analysis of product variants and customers

Company B primarily sold chemical solutions. These products made up approximately 70% of the collective revenue and were adequately similar in the way they were internally handled and produced. Therefore, the case study scope was limited to the in-house produced chemical end-products. Customers were denoted by two individual accounts based on industry or geographic location. These accounts were split, and the ABC analysis was conducted according to ship-to annotation. This means that if a sales order line consisted of a smaller regional customer (a ship-to account) and a joint customer account (a sold-to account), then the ABC rating was annotated based on the turnover and profit of the regional customer account. Sales data from a 24-month period were considered. This resulted in more than 2,400 sales order lines covering 467 end-product variants purchased by 1,004 customers.

The ABC analysis was conducted on product variants and customers. Both analyses were delimited by the 24-month period for sales data. To accurately denote the contribution, the customer ABC analysis was constructed using transactional data on the sold SKUs and the associated add-on services. The product ABC analyses were solely constructed on the sold SKUs. The distribution of ABC ratings is illustrated in Table 6. Most customers (66%) were rated as C-customers, while A-customers and B-customers collectively accounted for 34% of the customer base. A smaller number of customers, thus, accounted for the majority of the monetary contribution, which emphasises the need to consider linked revenue, as losing these customers would substantially affect the business performance.

Table 6 - Distribution of product variants and customers according to ABC categories in Case Study B

	No. of product variants	**No. of customers**
A	109 (23%)	157 (16%)
B	102 (22%)	180 (18%)
C	256 (55%)	667 (66%)

Step 2: Identification of relevant customers

Next, relevant customers were identified. In this context, Company B had a cautious and reluctant view of product portfolio reductions, which is why decisions were made to consider both A-customers and B-customers in the linked revenue setup. This means that if a product was purchased by either an A-customer or a B-customer, it was denoted as having linked revenue.

Step 3: Analysis of sales data for linked revenue

Based on the ABC analysis of products conducted in Step 1, a complete list of C-products was derived and linked to the customer purchase records. Following the set definition of Step 2, the linked revenue status could be determined by examining if an A-customer or a B-customer had purchased a C-product within the investigated period. This reduced the number of C-products eligible for termination from 256 to 53, meaning that 203 C-products were protected from termination due to having historically been purchased by customers associated with linked revenue. The remaining 53 C-products were further evaluated in the following steps.

Step 4: Identification of product variants to be protected from termination

In the fourth step of the proposed procedure, products exempted from portfolio reduction initiatives due to company-specific reasons were identified. In the case company, new product introductions were primarily derived from new generations and updates. Therefore, recently introduced products were evaluated on the same metrics as their counterparts and were not, by rule, protected from termination. However, products introduced within the investigated period were exempted from further investigation, as their performance could not be accurately and fairly evaluated against their counterparts'. Seven products were protected for this reason.

Furthermore, an array of products in the portfolio were direct byproducts derived from chemical side reactions in the production of other products. These products were produced as a natural consequence of the main manufacturing activities. Terminating them from the portfolio would change their annotation from saleable to waste and, therefore, would not lead to any significant complexity reductions. One product was protected for this reason.

Step 5: Development of termination scenarios

With the exemption process concluded, the remaining 45 products could be assessed by means of different termination scenarios. To construct the scenarios, six turnover groups were first devised from the conclusive list of 256 C-products. The C-products here were congregated by their accumulative turnover, as shown in Table 7.

Table 7 - Turnover groups in Case Study B

	Accumulative turnover	No. of product variants
Turnover Group 1	35%	6
Turnover Group 2	50%	15
Turnover Group 3	65%	22
Turnover Group 4	80%	33
Turnover Group 5	95%	62
Turnover Group 6	100%	188

This means that the best-performing C-products that have contributed to the accumulative turnover of up to 35% were distributed to Group 1, and the C-products not included in Group 1 that have contributed to the accumulative turnover of up to 50% were distributed to Group 2, and so on.

From the six turnover groups, four scenarios were designed to evaluate which of the products from the portfolio should be nominated for termination. This was done by defining a specific gross profit (GP) ratio (GPR) minimum for each group of products. If a product in any one group had a GPR higher than the predetermined minimum, the product would be exempted from termination. The four scenarios, illustrated in Table 8, were designed to reflect decreasing levels of caution, granting company stakeholders an opportunity to influence the magnitude of portfolio termination. For confidentiality reasons, the turnover and CMR values have been multiplied by a fixed factor.

Table 8 - Termination scenarios for Case Study B

Turnover per year	Minimum CMR for Scenario 1	Minimum CMR for Scenario 2	Minimum CMR for Scenario 3	Minimum CMR for Scenario 4
100,000+	Never terminate	Never terminate	Never terminate	Never terminate
100,000 – 57,200	Never terminate	10%	10%	20%
57,200 – 40,000	10%	15%	20%	40%
40,000 – 27,100	20%	35%	40%	60%
27,100 – 9,000	40%	50%	60%	Always terminate
9,000 – 0	Always terminate	Always terminate	Always terminate	Always terminate

After identifying the products nominated for termination according to each of the four scenarios, the impact of each scenario could be calculated, starting with computing the released production capacity. The day-to-day production capacity for each variant nominated for termination was supplied by the case company and linked to the sales order lines, from which the GP per production hour could be computed. The same procedure was followed to determine a comparable GP per production hour for an average A-product. The conclusive impact of each scenario was quantified by calculating the increase in GP resulting from utilising the released capacity to manufacture and sell an average A-product instead of the nominated C-product. This resulted in an increase in the annual GP between 0.60 and 1.14 percentage points. Table 9 shows the impact of each scenario.

Table 9 - Impact of termination scenarios in Case Study B

	No. of products nominated for termination	**Percentage point increase to annual gross profit**
Scenario 1	32	0.60
Scenario 2	38	1.06
Scenario 3	39	1.09
Scenario 4	42	1.14

Evaluation of usefulness and impact of the proposed procedure

As of the writing of this paper, Company B had not completed the two final steps of the procedure under study. Nevertheless, semi-structured interviews were conducted with a master data manager, two product line directors and a commercial finance director to understand the usefulness of the procedure and the impact of the product variety reduction initiative. In this context, the master data manager is responsible for maintaining and updating master data on the product level, which encompasses data on the termination process when a decision to terminate a product has been made. Furthermore, the master data manager will partake in product portfolio reduction discussions and propose products for termination. The product line directors are responsible for the product portfolio and have the conclusive say as to which products to terminate. The commercial finance director has no direct influence on the product portfolio but is employed to support the commercial organisation in achieving its strategic ambitions through improvement initiatives.

The master data manager recognised the procedure as being a useful tool to identify unprofitable products that can be terminated without risking the business of important customers. They also described it as a useful tool for communicating the rationale for terminating specific product variants and for identifying reasons why already terminated products should be re-opened. They believed that the procedure should be conducted once per year going forward. In general, they agreed with the proposed steps identifying products that should be protected from termination despite performing poorly financially. They also agreed with the method used in the procedure to quantify the impact of termination items, namely, by calculating the production capacity that will be released and converting this value into the profit earned if A-products were produced instead.

The product line directors stated that the approach currently applied in Company B for reducing product variety is not very systematic. They, therefore, perceived the proposed procedure as useful for systemising, automating and guiding the process of product variety reduction. Also, they believed that the procedure would create significant value for the company and that it should be conducted every year henceforth. According to the product line directors, the biggest obstacle to implementing the procedure seemed to be data quality and process transparency. On this basis, they emphasised the particular importance of being completely transparent regarding the sales data used, the costs included and the rationale for nominating products for termination, which was facilitated by the procedure.

The commercial finance director recognised the approach as a valid and systematic strategy to product portfolio maintenance. He expressed that a periodic evaluation of the product portfolio, following the proposed method, would align nicely with the strategic ambitions of the commercial organisation.

Comparison of the results of the two case studies

In this section, the results of the two case studies are compared, and the usefulness of the proposed procedure is evaluated.

Results from projects in which the proposed procedure was applied

Figure 2 outlines the process for identifying products to be terminated according to the proposed procedure for the two case studies. The total number of product variants within the scope of the two cases varied significantly. In case study A, 902 C-products were identified, while in case study B, 256 C-products were identified. However, the processes followed in each case were relatively similar, with the only significant difference occurring when identifying products to protect due to being purchased by customers with linked revenue. More specifically, in case A, 53% of C-products were protected from termination due to having been purchased by customers with linked revenue, while in case B, 79% of C-products were protected from termination for this reason. This difference was a result of the ways in which customers with linked revenue were identified in each case. Company A served two separate customer segments, of which only one was defined as being prone to linked revenue. This means that products purchased by customers in the segment not prone to linked revenue were not protected from termination, even if the customers were categorised as A- or B-customers. In Company B, on the other hand, all customers were identified as being prone to linked revenue, meaning that all products purchased by A- and B- customers were protected from termination, regardless of which customer segment was responsible for their purchase.

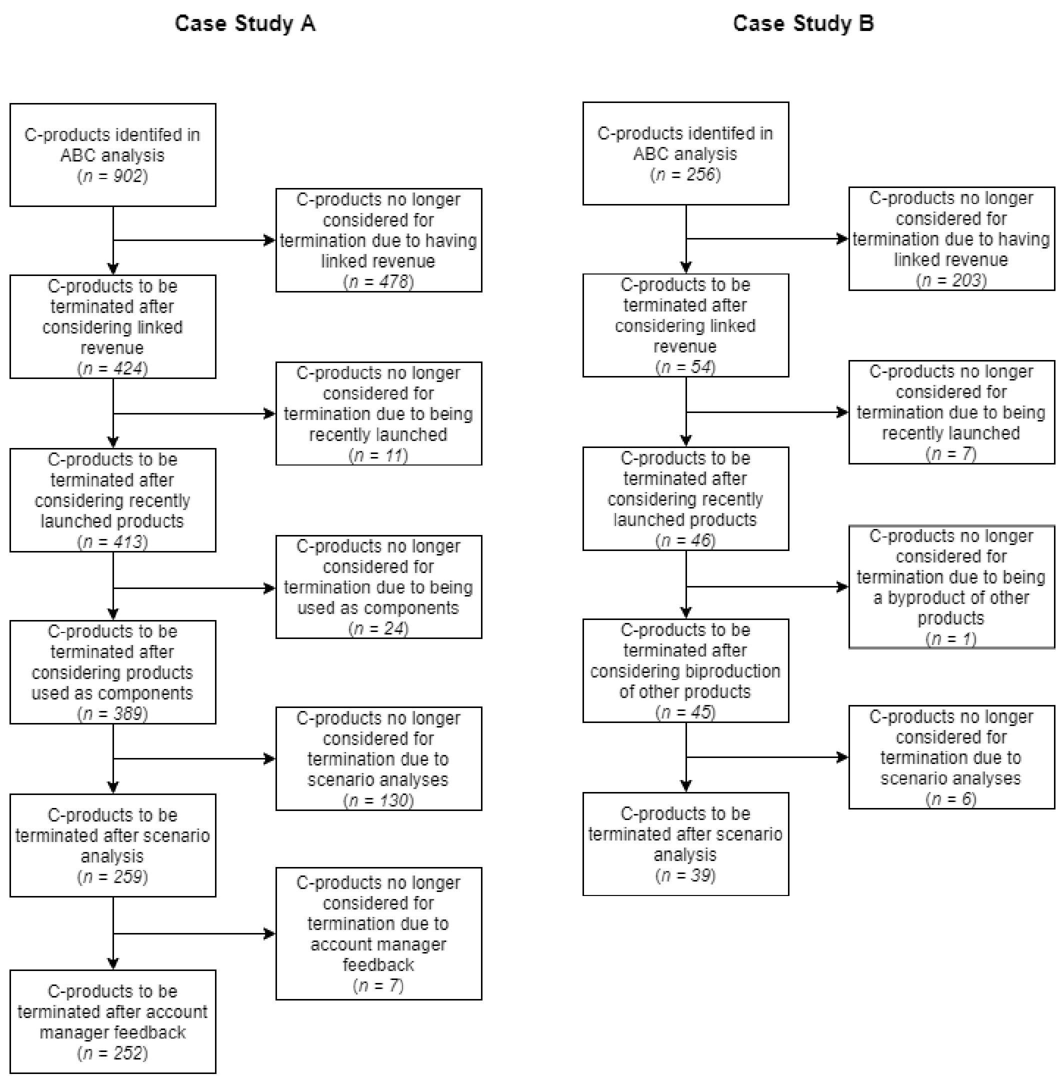

Figure 2 - Processes for identifying products to be terminated in the two case studies

Despite the difference in the number of unprofitable products identified in the two case studies that could be terminated without risking the linked revenue of vital customers, the expected impacts of terminating these products were considerably similar. Specifically, in the first case study, the expected impact was an increase in the annual contribution margin of between 0.63 and 1.84 percentage points, depending on the selected scenario, while in the second case, the expected impact was an increase between 0.60 and 1.14 percentage points in the annual GP.

Effects of the proposed procedure

As mentioned previously, to fully determine the value of the proposed procedure in each case study, scenarios were devised and analysed to explore what would have happened if linked revenue had not been considered, which was done by quantifying the impact of using the procedure without protecting products that were purchased by customers with linked revenue (i.e. skipping Step 3). The results of these analyses are illustrated in Figure 3 and Figure 4. The leftmost bar in the figures represents the number of C-products identified in each case. This bar is then split into three parts: the bottom part represents the products nominated for termination as a result of following the procedure; the middle part represents the products that would have been nominated for termination if linked revenue had not been considered; and the top part represents the products that were not recommended for termination as a result of the evaluation conducted in Step 5. The middle bar represents the customers who purchased the products from the leftmost bar. In this bar, the top part represents the customers who were defined as having linked revenue, and the bottom bar represents the customers who were defined as not having linked revenue. Finally, the rightmost bar represents the turnover realised by the case company from the customers in the middle bar. The top part of this bar represents the total annual of turnover associated with customers with linked revenue, while the bottom part represents the total annual turnover associated with customers without linked revenue.

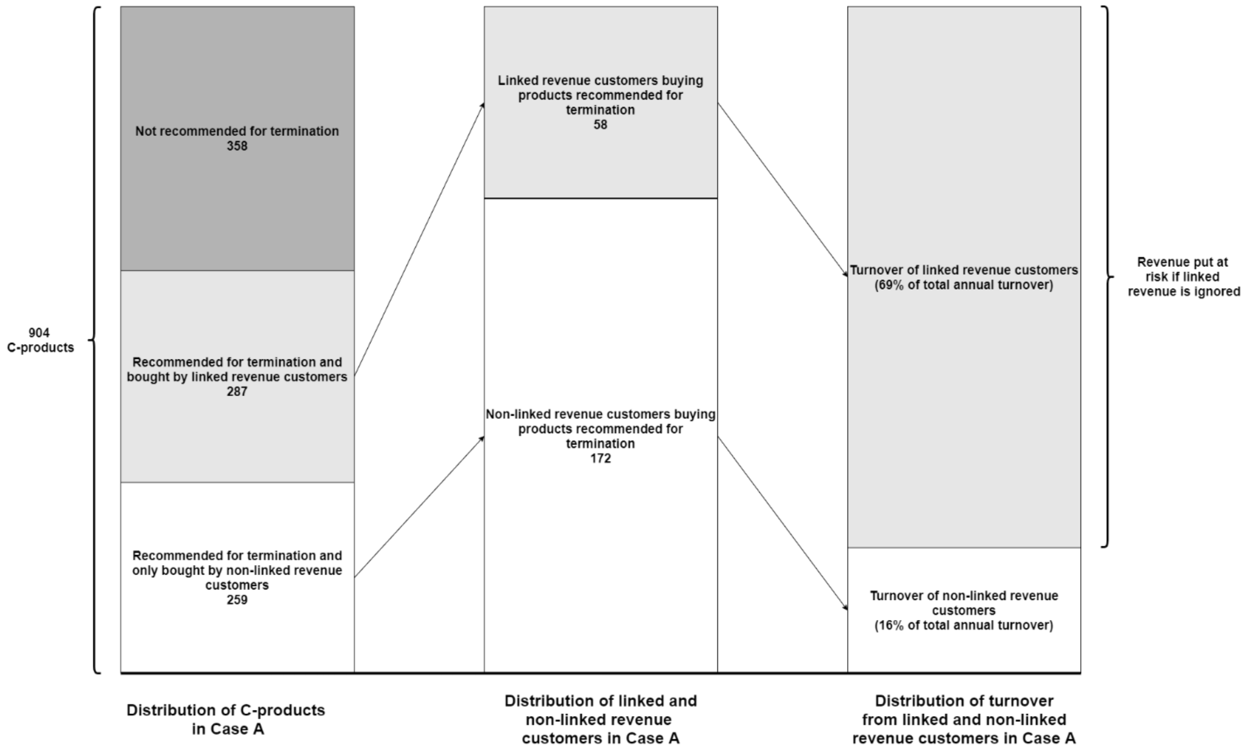

Figure 3 – The effect of the proposed procedure in Case Study A

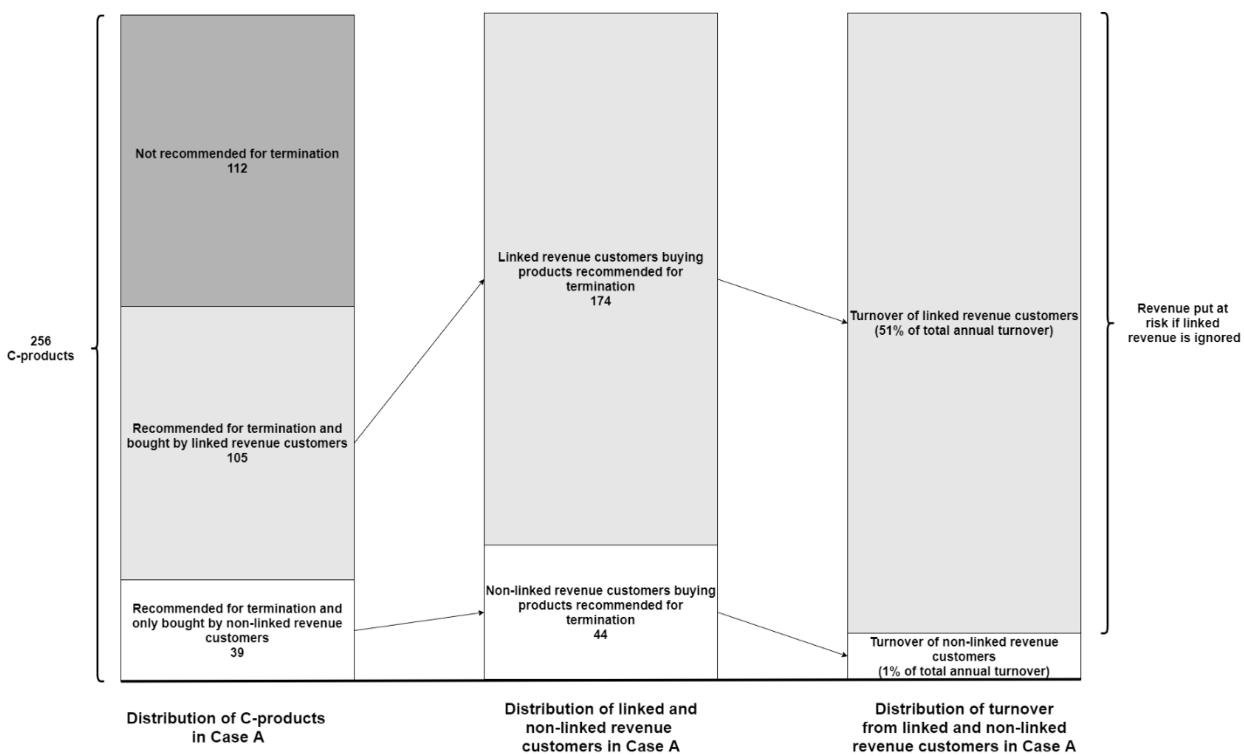

Figure 4 - The effect of the proposed procedure in Case Study B

As seen by comparing Figures 3 and 4, the composition of the middle bar differs in the two cases. In the first case, relatively few customers with linked revenue are identified, compared to the number of customers with linked revenue in the second case. A reason for this, as explained previously, is that case company A serves two separate customer segments, and only one is prone to linked revenue. Therefore, no customers from the other segment are associated with linked revenue, regardless of their sales numbers. Also seen in Figures 3 and 4 on the rightmost bar, in case A, 69% of the total annual turnover is generated by customers with linked revenue who purchased one or more of the 287 products that would have been recommended for termination if linked revenue had not been considered. Hence, 69% of company turnover would have been put at risk if linked revenue had not been considered. On the other hand, in case B, 51% of total annual turnover was generated by customers with linked revenue who purchased one or more of the 105 products that would have been terminated if linked revenue had not been considered. These results illustrate the importance of considering linked revenue when reducing product variety.

Conclusions

Based on an existing method for reducing product variety (Hvam et al. 2019), this article presents an approach to reduce product variety while minimising the loss of business from vital customers through consideration of *linked revenue*. The proposed procedure (1) identifies products that are unprofitable and can be terminated without impacting the business of the most profitable customers, (2) evaluates the potential profitability of these products and (3) reduces internal pushback on product terminations by involving affected customer account managers. The proposed process was tested in two separate case studies to assess its usefulness. Both cases showed that the procedure enabled great reductions in product variety, while at the same time preventing the termination of products with linked revenue, thereby avoiding related losses.

Implications for research

The study contributes to the existing literature on the management and reduction of complexity (Closs et al. 2008; Escobar-Saldívar et al. 2008; Haug et al. 2013; Hvam et al. 2019; Myrodia and Hvam 2014) by proposing a new method to identify products for termination while minimising the resulting loss of business from profitable customers. As demonstrated by the literature review, existing methods for product variety reduction do not consider linked revenue; consequently, they may call for the termination of products that are important to certain customers, who may look to other suppliers as a result. As the proposed procedure prevents this, it represents a further development in this research stream. Moreover, by defining the concept of *linked revenue* and demonstrating its relevance, the study provides important insights for future product variety management research. Specifically, as demonstrated by the present study, *linked revenue* is a concept that is highly important to consider in research investigating or providing methods for product variety reduction.

Implications for practice

The results of the two case studies showed the usefulness of the procedure for practitioners. The data required to conduct the analyses was readily available in both case companies, resulting in relatively problem-free and fast implementation. Managers in both companies expressed positive views on the usefulness of the approach and expressed wishes to include the approach as an annually returning project and as a method to gain insights into customer purchasing behaviour. Thus, as compared to existing approaches, the present paper provides manufacturing companies a tested procedure for reducing their product variety while avoiding the loss of business from vital customers by failing to consider linked revenue.

Limitations and future research

The approach was tested in two case companies, limiting the generalisability of the findings. However, the challenges addressed by the approach are commonly experienced in manufacturing companies in general. Furthermore, the data required to conduct the analyses described in the approach should be easily available in most manufacturing companies. Therefore, we argue that the findings can by generalised.

As mentioned, we worked with a binary definition of linked revenue. The approach can be modified to include a more elastic definition of the concept. However, this would require additional data and knowledge regarding both products and customers, which would complicate the analysis.

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Data availability statement

Supporting data is not available, due to commercial confidentiality restrictions.

Disclosure statement

No potential conflict of interest was reported by the author(s)

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Study C

Paper title	An approach for the development and implementation of configurators for product- related services
Authors	Tobias Kondrup Andersen, Lars Hvam, Anders Haug
Paper type	Journal paper
Outlet	Computers in Industry
Paper status	Accepted with revisions

An approach for the development and implementation of configurators for product-related services

A significant part of traditional manufacturing companies' value propositions is provided through their product-related services, such as transport terms, packaging, documentation, installation, and support. However, it is challenging for many companies to manage such services, as the characteristics of individual services differ significantly from one another. To support manufacturing companies' service specifications and price calculations for individual customers, in this paper, we argue for the use of configurators in such processes. Product configurators are widely used in product development and sales processes in engineer-to-order (ETO) companies, and several approaches to the development and implementation of this technology can be found in the literature. In comparison, the use of configurators for service specification has not yet received much research attention. Thus, to support manufacturing companies' adoption of this technology, we propose an approach to the development of a configurator for product-related services. This approach is then tested through a case study, which demonstrates its usefulness. In particular, the case company achieved four main types of benefits upon implementing a service-related configurator using the proposed approach: (1) increased service cost accuracy, (2) increased service price transparency, (3) improved differentiation according to customer characteristics, and (4) more formalized and well-structured service specifications.

Keywords: product-related services, servitization, configurator, configuration systems, service configurator, manufacturing firms

1 Introduction

Traditional manufacturing companies offer a range of physical products as their core offerings. However, a significant part of their value proposition is provided through product-related services (Vandermerwe & Rada, 1988). Examples of product-related services include transport terms, packaging, documentation, installation, and support. However, it is quite challenging for many companies to manage their product-related services, as each service can differ significantly from the others (Raja et al., 2018). Furthermore, adopting a servitization strategy implies that companies must find new ways of organizing their resources to provide services efficiently and effectively (Hakanen et al., 2017).

The ETO product development and sales processes face challenges similar to the creation of customer-specific services, given the uniqueness of each product. To address these challenges, product configurators are widely used in such companies. The literature reports on a multitude of benefits that can be obtained from the use of product configurators in ETO companies, including increased development process efficiency, reduced person-hours, improved product quality, and shorter lead times (Ardissono et al., 2003; Becker & Klingner, 2015; Hvam et al., 2008a, 2013; Kristjansdottir, Shafiee, Hvam, Bonev, et al., 2018; Kristjansdottir, Shafiee, Hvam, Forza, et al., 2018). Several approaches for the development of product configurators have been proposed (Forza & Salvador, 2006; Haug et al., 2012, 2019; Hvam et al., 2006, 2008b), but these traditionally only include physical products. One exception is Mueller et al. (2022), who developed and tested an approach to developing a service configurator for the commissioning of complex ETO products. However, the issues and challenges of developing a configurator for product-related services differ significantly from those involving the development of configurators for commissioning services. As a result, their approach does not focus on the process of mapping and evaluating existing product-related services to select which product-related services to include in the scope of the configurator. Additionally, the configuration of product-related services differs from other types of services in that they are deeply connected to the selection of customers and physical products. The selection of specific customers and products directly dictates both the availability and the cost of the product-related services, which existing approaches to configurator development have failed to consider.

To address the literature gap described above, this paper first refers to past studies to establish an approach to the development and implementation of product-related service configurators. Next, the usefulness of the approach is tested through a case study at a medium-sized Danish manufacturing company. Finally, the study's conclusions are drawn based on the findings.

2 Development of configurators for product-related services

In the following sections, we explore product-related service definitions and approaches to help lay out a basis for an approach for the development and implementation of configurators for product-related services.

2.1 Product-related services

Manufacturing companies are moving from primarily selling physical products to offering an increasing array of services to support these products (Guillon et al., 2021). In this context, Tukker (2004) describes three main classifications of services: (1) result-oriented services, where the provider and buyer agree on a result without defining the products to be used; (2) use-oriented services, where the buyer purchases the right to use a physical product while it is still owned by the provider; and (3) product-oriented services that are sold in additional to a physical product, while the latter is still considered the main offering. Product-oriented services are further split into two categories: (1) *advice and consultancy*, where the supplier offers advice on the most efficient use of a product, and (2) *product-related services*, which refer to services that are needed during the use phase of a product.

Different types of product-related services exist, including maintenance, financing schemes, takeback agreements, training, etc. (Guillon et al., 2021; Lenfle & Midler, 2009; Tukker, 2004). These can be organized according to the specific product lifecycle phases during which they are produced by the supplier. For example, shipping method and order-tracking services occur during the transport phase, while maintenances service occurs during the use phase. While offering product-related services can be highly profitable, many companies struggle to determine which services to offer and how they should be defined (Cusumano et al., 2010; Raja et al., 2018).

The cost and availability of product-related services are mainly governed by the characteristics of the specific physical products being sold and the customers to whom they are sold (Guillon et al., 2021). For example, various express shipping services might be available only to customers located in certain countries, and the shipping cost is directly connected to the dimensions and weight of the products being sold. Thus, if a manufacturing company decides to offer product-related services, it is important to clearly define which services should be offered to different customer groups and to understand the costs associated with offering these services. This is because if a company is not in control of which services it can offer to customers, then it risks promising services that are impossible to provide. Furthermore, if companies are not aware of the costs of offering their product-related services, they risk underestimating the actual cost of providing such services and committing to customer contracts that end up not being profitable. Alternatively, they also risk overestimating the cost of providing these services, thus demanding non-competitive prices from the market and losing potential business (Benedettini et al., 2015; Raja et al., 2018).

2.2 Approaches for the development of configurators

Several approaches for the development and implementation of configurators have been proposed in the literature (Forza & Salvador, 2006; Haug et al., 2012, 2019; Hvam et al., 2006, 2008a). However, these approaches focus on the configuration of physical products and do not address the question of how to include services. As mentioned earlier, only one study (Mueller et al. 2022), has proposed an approach to the development and implementation of a service configurator, which synthesized existing approaches to a single approach focusing on complex ETO commissioning services. As previously mentioned, this approach does not consider certain aspects relevant to product-related services.

Although no approaches for developing and implementing configurators for product-related services can be found in the literature, some articles have discussed relevant insights that can be used when developing such an approach. One such insight is the concept of service modularization. Just as physical products can be broken down into sets of components or modules (Aldanondo & Vareilles, 2008; Schierholt, 2001; Zhang et al., 2013), services can similarly be broken down into modules (Böttcher & Klingner, 2011) despite services are intangible (Guillon et al., 2021). To develop service configurators, they must be based on a modular service architecture (Hellström et al., 2016) that should be visualized using visualization techniques, such as process graphs (Cao et al., 2006; Schierholt, 2001). Additionally, when modeling service offers, it is important to consider the context in which an offer is taking place (Guillon et al., 2021), including the market state, customer profile, the future state of the company, and customer requirements. These insights will be considered in the following sections when establishing an approach to developing and implementing configurators for product-related services.

2.3 An approach for the development and implementation of product-related service configurators

In this section, an approach for the development and implementation of product-related services is developed based on existing approaches for developing and implementing configurators (Haug, Hvam, and Mortensen 2012; Hvam et al. 2019; Hvam, Mortensen, and Riis 2008; Forza and Salvador 2006; Mueller et al. 2022) while modified to handle product-related services. The developed approach is shown in Figure 1, and the five overall steps and their related sub-steps are described.

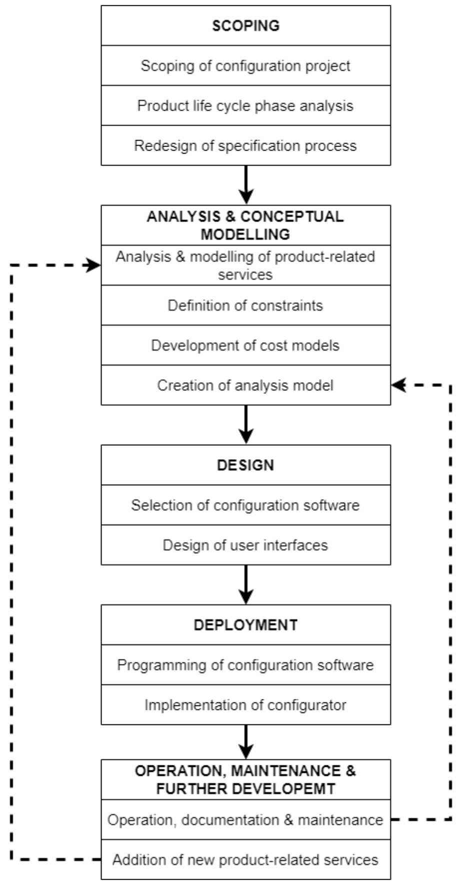

Figure 1 - An approach for the development and implementation of product-related service configurators

2.4 Step 1: Scoping

2.4.1 Scoping of the configuration project

The overall requirements of the configurator are defined based on an analysis of the needs of the company. These requirements include the level of application, the characteristics and needs of the end-users, and which parts of the product and customer portfolio must be included.

2.4.2 Product lifecycle phase analysis

In this part of the process, analyses are conducted to identify all product-related services offered by the company throughout its products' lifecycle phases. For each phase, domain experts are gathered at a workshop, and all product-related services connected to the lifecycle phase are listed. The analysis is structured in this way to ensure that no product-related services are overlooked and to better structure the output of the analysis. When the list of product-related services is finished, the next step is to decide which of them to include in the scope of the configurator. This decision should be made based on three criteria: (1) cost, (2) data quality/availability, and (3) customer value.

First, product-related services that are costly to deliver to customers have a higher impact on the total cost of the final offering. Given that the pricing calculation is impacted more heavily by these costly product-related services, they should thus be prioritized during the scoping of the configurator. Furthermore, product-related services with unevenly distributed costs across individual offerings are more suitable candidates to be included in the configurator. Even if offering a product-related service entails a higher cost, if the cost represents a fixed and flat value for all offers, it will not create much value when it is included in the configurator.

Second, data regarding all existing service variants related to each product-related service is required. Furthermore, data regarding the costs associated with delivering each of the defined variants are required. Therefore, product-related services with high data quality and availability should be prioritized during the scoping of the configurator. If data on the variants offered or the associated costs do not exist or are of low quality, such data must be collected. This can be a lengthy and expensive procedure as it might require extensive process analyses and time studies.

Third, it should be noted that even if a product-related services is not costly to deliver, it being valuable to customers represents an opportunity for a company to increase sales prices and, therefore, the contribution margin of the final offering. Thus, product-related services that are of high value to customers should be prioritized in the scoping of the configurator.

Each identified product-related service should be ranked according to these three criteria. Based on the results, a decision on which services to include should be made. Table 1 - Quantification of which product-related services to include in the scope of the configurator

presents an example of how to structure this ranking process.

Product-related Service	**Cost**	**Data quality/availability**	**Customer Value**	**Total Score**
Shipping Method	5	5	3	13
Order Tracking	2	5	2	9
Installation	3	3	4	10
….	…	…	…	…

Table 1 - Quantification of which product-related services to include in the scope of the configurator

2.4.3 Redesign of the specification process

The purpose of this step is to redesign the product-related service specification process so that it can handle the requirements of the new configurator. First, the current specification process in the company is mapped.

This includes the full specification process within the scope of all product-related services. Therefore, relevant domain experts for each product-related service should be consulted. This process is visualized using flowcharts or graph models. In accordance with the knowledge of the current specification process, the process is then redesigned to handle the previously defined requirements. Finally, the redesigned specification process is visualized.

2.5 Step 2: Analysis and conceptual modeling

2.5.1 Analysis and modeling of product-related service variants

One requirement for creating a service configurator is that it must be based on a modular service architecture (Hellström et al., 2016). Therefore, a modular architecture is modeled for each product-related service. Workshops with relevant domain experts are conducted to map all existing service variants for each product-related service. After listing all existing variants, it might become apparent that it would be beneficial to reduce their numbers. The remaining service variants are defined as being included in the scope of the configurator, and additional workshops are held to define the final modular architecture of these services. This includes the definition of the modules to eventually comprise the services as well as the attributes required to describe them.

2.5.2 Definition of constraints

When configuring product-related services, the solution space is mainly governed by the selection of product variants and customers. These constraints have a twofold purpose. First, constraints prevent users from creating impossible configurations. For example, by preventing the packing of items exceeding certain physical dimensions into boxes that are too small to contain them. Second, constraints can strategically prevent users from offering services that a company has decided not to provide to specific groups of customers, such as preventing same-day express shipping to customers located in a certain region.

Each product-related service variant is analyzed, and constraints are defined at workshops with relevant domain experts. In this context, it should be noted that the people who define the constraints of a configurator are often not the same as those who program the configuration software. Therefore, constraints should be expressed in a way that is simple to understand for both groups of people. One option is to express constraints as lines of pseudo code or in the form of constraint tables (Hvam et al., 2008a)

2.5.3 Development of cost models

In accordance with the product, customer, and product-related services selected, the configurator should calculate the specific cost of each product-related service separately. The total cost of the offering is then calculated by summing the costs of each service. Therefore, a customized cost model should be designed for each product-related service within the scope of the configurator. The first step is to decide on the desired format for the output of each cost model. For example, the output can be expressed as the product-related service cost per unit of products sold or as the total product-related service cost across the total quantity of products in the offering. The output should be expressed using the same format for each cost model to enable the configurator to easily calculate the total cost of the offering by simply summing the costs of each individual service in the configured offer.

The cost of providing product-related services for individual offers is directly connected to the characteristics of the selected products and customers. For example, the cost of shipping a pallet of products from Denmark to a customer located in Germany is lower than shipping it to a customer located in Australia. Furthermore, the shipping and order handling costs incurred by shipping ten products in a single order are lower than the cost of shipping one product in ten separate orders. The cost is also directly related to the specific service variants selected. In 2.5.1, each product-related service was modeled to have a modular architecture and the service variants to be included in the configurator were finalized. Now, projects are initiated to collect and record data on the costs of each service variant. For example, if the installation is included as a product-related service, then data should be collected regarding the cost related to installing different types of products. These costs should be incorporated into the cost models.

The nature of what drives the cost of a product-related service differs depending on the type of service. Some services are directly driven by the number of products sold (e.g., the cost of installation is the same for each product sold), while other services represent a fixed cost per order (e.g., offering customers order tracking incurs a fixed cost per order). Therefore, the cost per sold product for this service decreases as the quantity of products in each order increases. A third type of situation is wherein services represent a fixed cost, regardless of the number of products sold or orders placed. One example is the cost of creating a documentation report detailing the characteristics of a product, for which the service cost per sold product decreases when the total number of products sold increases because the cost is split evenly across each unit sold. Figure 2 illustrates the nature of product-related service costs with different cost drivers.

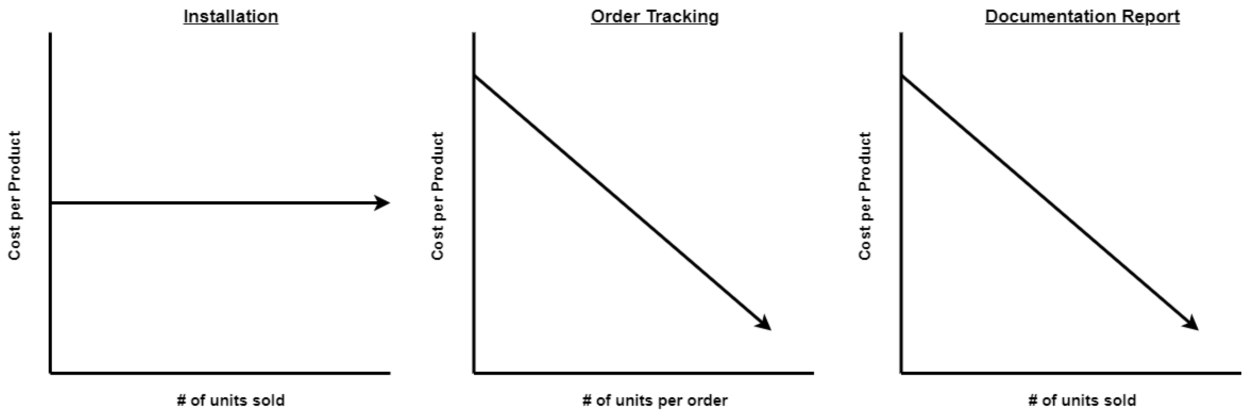

Figure 2 - Product-related services with different cost drivers

Separate workshops should be conducted for each product-related service. At these workshops, domain experts analyze and identify the cost drivers relevant for each product-related service and design cost models that incorporate these cost drivers and express the output in the desired format. Depending on the complexity of the product-related service, several iterations of cost models might be required to reach a sufficiently accurate result. Furthermore, it might become apparent that additional analyses must be conducted to collect the required cost data to be used in the cost models.

2.5.4 Creation of the analysis model

All customers, product variants, and product-related service variants were to be gathered into an analysis model to illustrate the modular structure of each product-related service. This model also should contain all the defined constraints and the developed cost models. The purpose of the analysis model is to include all kinds of information required to understand the structure and logic of the configurator and to be used as the basis for programming the configurator in the selected software shell. As configurator development requires inputs from stakeholders and domain experts from different departments within a company, each with different levels of modeling experience, the modeling technique used for the analysis model should be relatively simple to understand. Thus, we suggest using the product variant master (PVM) as this modeling technique is easy to learn and read (Haug et al., 2012).

A PVM typically contains a *Customer View* that describes choices related to the customer and a *Part View* that describes the specific physical components to be used in the final product. This traditional PVM structure is extended with a *Product-Related Service View*, in which each product lifecycle phase is represented as a separate module. These modules contain product-related services that are connected to the product lifecycle phase. Figure 3 shows an example of a simple analysis model in the shape of a PVM. In this simplified example, the customer view includes data on the customer segment and geographical location. Similarly, the product view contains all relevant information about physical products within the intended scope. In this case, an attribute table shows the product family and the number of pallets that one unit of product takes up during freight. The product-related service view is grouped into three product lifecycle phases: distribution, installation, and use. Each phase contains a product-related service consisting of anywhere from one to three separate modules. For instance, the product-related service called *shipping* is made up of a *shipping method* and an *order-tracking* module. The *shipping method* dictates whether the product will be shipped with a standard delivery lead time of five weeks or with an express delivery lead time of two weeks. Obviously, the costs of these two service variants differ. The *order-tracking* method dictates whether a customer receives the order-tracking information on a weekly or daily basis. The cardinality of this module [0,1] illustrates that if a customer is not interested in this service, it can be omitted from the offering. Under each product-related service, the related constraints are presented. These constraints explain how the solution space of this specific product-related service is limited by the selection of customers, products, or even other product-related services. For example, a constraint on the shipping service explains that if the region of the customer is *North America,* then only *standard shipping* is available. Finally, the cost models developed to calculate the cost of each product-related service are presented below the constraints. As can be seen, the output of all cost models is expressed as the total product-related service cost per order.

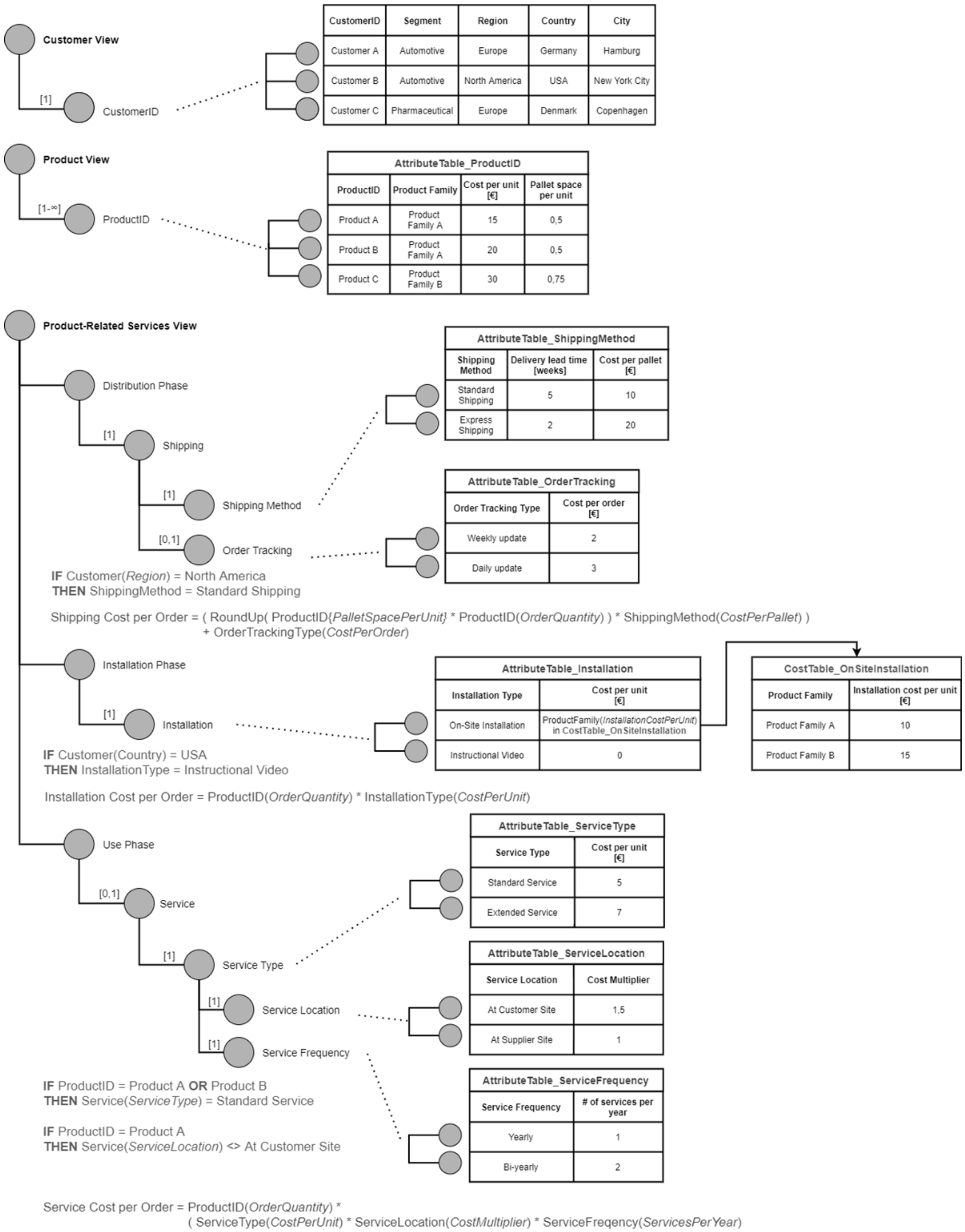

Figure 3 - Example of a simplified PVM with product-related services, constraints, and cost models

2.6 Step 3: Design

2.6.1 Selection of configuration software

Whether to use an existing configuration software shell or to develop custom configuration software from scratch is decided in this step. Some commonly used configuration software shells include Configit Product Modeler, Baan Product Configurator, Oracle Configurator, Tacton Configurator, and Cincom Knowledge Builder (Haug et al., 2012). However, companies might also decide to build their configurators from scratch if such standard solutions do not fit their demands or if they prefer to avoid paying license fees.

2.6.2 Design of user interfaces

The most appropriate user interfaces for a configurator depends on two factors: the type of user and the purpose of the system. Therefore, workshops should be conducted with the end-users of the system to come up with a consensus regarding the user interfaces that will be used in the final configurator. The chosen design must ensure that users are provided with the relevant information at the appropriate time and that they are guided throughout the process of creating a configuration. This includes both the order in which the inputs will be made and the visual design of each interface. Flowcharts and mock-ups should also be created to better present and discuss various options. Additionally, it is possible to develop automatic prompts providing users with relevant information based on their inputs. For example, the system might notify the users if an alternative and similar service variant exists that would be cheaper to offer based on the inputs.

2.7 Step 4: Deployment

2.7.1 Programming the configuration software

During this step, the configuration software is programmed using the scope, attributes, constraints, and calculations defined in the analysis step.

2.7.2 Implementation of the configurator

In this step, the configurator is tested and possibly adjusted, and users are trained in its use. It is important to educate the users of the system so that they can better understand each of the product-related services and their individual service variants. Prior to launching the configurator, all departments and internal systems should be able to deliver the product-related service variants defined in the configurator.

2.8 Step 5: Operation, maintenance, and further development

2.8.1 Operation and maintenance

As changes occur regarding the service variants offered by the company or the cost structure of the services, both the analysis model and the configurator should be updated to reflect these changes.

2.8.2 Further development

The modular nature of analysis model facilitates easier extensions to the configurator. For instance, if users wish to add a new product-related service, they simply need to create a new module under the relevant product life-cycle view in the analysis model and continue to model the attributes, constraints, and cost calculations. As the cost of a service is calculated individually for each view, this can be easily added to the system.

2.9 Comparison with existing approaches

The most significant difference between the proposed approach for development of product-related service configurators and existing ones aimed at products concern the first and second steps. Specifically, during the first step (Scoping), the proposed approach includes a systematic process of identifying existing product-related services in a company and evaluating these services to decide which to include in the scope of the configurator. For the second step (Analysis and conceptual modeling), due to the availability and cost of individual product-related services being directly tied to the characteristics of the selected customer and products, the proposed approach includes processes for defining the necessary constraints and developing the cost models to be included in the configuration system. The constraints restrict impossible and unwanted combinations of customers, products, and product-related services from being selected, while the cost models govern how the costs of each product-related service is to be calculated based on the selected customers and products. Furthermore, the traditional analysis model has been extended to include product-related services structured in a modular architecture. The remaining steps are not significantly modified compared with existing approaches.

3 Research method

To investigate the usefulness of the proposed approach for the development and implementation of product-related service configurators, a case study approach was chosen. Case studies facilitate in-depth explorations into the phenomenon and are useful for theory testing (Yin, 2018). The case company was chosen because of its use of the proposed approach for the development of a product-related service configurator.

The case company is a Danish manufacturer of plastic components with approximately 200 employees and an annual turnover of 23 million euros. Prior to this study, the process of specifying product-related services was conducted manually. Sales personnel specified the products to be quoted, from which suggested sales prices were calculated. After this, the product-related services were manually selected from a list, and a fixed service cost was added to the quote. The selection of product-related services was not constrained by the selected customers or products, which led to the risk of creating quotes containing impossible combinations of customers, products, and product-related services. Furthermore, the cost calculations of product-related services were not connected to the characteristics of the individual quotes, which led to low service cost transparency. For example, the old cost calculation assumed the same shipping cost independently of the volume of each shipment. This brought with it a risk of over- or underestimating the cost of individual quotes. The concern was that if costs were overestimated for some quotes, this could lead to non-competitive pricing offers. Alternatively, if costs were underestimated, this could lead to offering prices that, ultimately, would not be profitable for the company. Thus, it was a priority from the management team at the company to increase the cost transparency for product-related services, thereby ensuring that pricing decisions were made as accurately as possible.

3.1 Data collection and analysis

The case study was split into two parts. The purpose of the first part was to test the usefulness of the developed approach in an industrial setting. The approach was applied to develop and implement a configurator for product-related services at the case company. This project was carried out over a nine-month period starting in 2021. During this time, the researchers attended workshops and meetings to gather participatory observations. The researchers were not allowed to record at the workshops and meetings, but we were allowed to take extensive notes (equivalent to approximately 50 normal pages) in Microsoft OneNote, which we then used to extract general observations and experiences about the project. Table 2 describes the workshop and meetings. Sensitive data, including cost values, product names, and customer names, were anonymized in the presentation of the case study due to confidentiality concerns.

Data Collection Purpose	Data Collection Method	Attendees	Duration
Determine the usefulness of the approach during the scoping step	Participatory observations at the workshops and meetings	1 Chief Operations Offer 1 Global Product Manager 1 IT Operations Specialist 1 Financial Controller 1 Head of Marketing 1 Warehouse Manager 1 Logistics Assistant 1 Document Engineer 1 Validation Manager 1 Supply Chain Manager 1 Configuration Expert	1 meeting (120 minutes) 4 workshops (60–90 minutes each)
Determine the usefulness of the approach during the analysis and conceptual modeling step	Participatory observations at the workshops	1 Global Supply Chain Manager 1 Logistics Assistant 1 Master data specialist 1 Customer Service Manager 1 Document Engineer 1 Validation manager 1 IT Manager 1 Financial Controller 1 Configuration Expert 1 Software Developer	15 workshops (60–120 minutes each)
Determine the usefulness of the approach during the design step	Participatory observations at the meetings	1 Software Developer 1 Configuration Expert 1 Global Product Manager 1 UI Designer 1 Master Data Specialist	3 meetings (30–90 minutes each)
Determine the usefulness of the approach during the deployment step	Semi-structured interviews	1 Software Developer 1 UI Designer 1 Global Product Manager	3 interviews (30–60 minutes each)
Determine the usefulness of the approach during the operation, maintenance, and further development step	Semi-structured interviews	1 Software Developer 1 Global Product Manager 1 Marketing Manager	3 interviews (30–60 minutes each)

Table 2 - Data collection during the first part of the case study

The purpose of the second part was to assess the benefits gained by using the developed configurator compared with the existing manual specification process used in the case company. Therefore, real order data were collected, validated, and used to test and compare the performances before and after the implementation of the configurator. The purpose of the tests was to study the impact of the configurator on service cost transparency and service price accuracy. Semi-structured interviews were conducted with company experts to confirm the validity of the data used for the tests and the results achieved from the tests. Additional interviews were conducted to identify additional benefits gained from using the new configurator. Table 3 describes the workshops and interviews.

Data Collection Purpose	Data Collection Method	Attendees	Duration
Collect and validate test data	Workshops	1 Master Data Specialist 1 Global Product Manager 1 Sales Representative	2 workshops (60 minutes each)
Conduct tests to compare the manual process and the configurator	Workshop	1 Software Developer 1 Configuration Expert	1 workshop (90 minutes)
Validate the test results	Semi-structured interviews	3 Sales Representatives 1 Global Product Manager 1 Financial Controller 1 Project Manager	4 interviews (30–60 minutes each)
Identification of the additional benefits gained	Semi-structured interviews	2 Sales representatives 1 Marketing Manager 1 Global Product Manager 1 Financial Controller	4 interviews (30 minutes each)

Table 3 - Data collection in the second part of the case study

To evaluate the configuration, its performance was compared to the results achieved by using the existing manual specification process. The comparison was done using more than 40 offers based on real order data, and the results were presented, discussed, and verified with company experts.

4 Case study

This section describes the phases of the project studied, in which the proposed approach to the development and implementation of product-related service-configurators was applied. Then, the effects of using the new configurator are evaluated and discussed.

4.1 Scoping

4.1.1 Scoping of the configuration project

An initial analysis was conducted to determine the needs for a configurator in the case company. Based on the obtained information, the level of application and purpose of the project were finalized. The configurator was to be used by the sales personnel to develop customized offerings to customers, including both physical products and several product-related services. Based on the selected products and services, the expected costs of delivering the proposed offerings were to be calculated and the suggested sales prices should be calculated based on the desired contribution margin ratio. Alternatively, the salesperson should be able to input a sales price for each offering, and the system was to then calculates the resulting contribution margin ratio.

4.1.2 Product lifecycle phase analysis

The next step was to create a comprehensive overview of the product-related services offered by the case company to its customers. At the workshops held with company domain experts, each product lifecycle phase was systematically analyzed, and all existing product-related services were listed for each phase. The following seven lifecycle phases were identified: sales, development, production, packing, storage, distribution, and use and disposal. By systematically analyzing each product lifecycle phase, a total of 29 product-related services were identified. Due to confidentiality considerations, the full list of product-related services is not presented.

Having identified all product-related services, the next step was to decide which ones to include in the scope of the configurator. This decision was made based on three criteria, namely, cost, data quality/availability, and customer value. At a workshop with relevant company experts and stakeholders, each of the 27 identified product-related services were discussed, evaluated, and given a score between 1–5 for each criterion. The total scores were summed, and the four highest scoring product-related services were decided to be included in the scope of the configurator. Due to confidentiality concerns, the scores are not presented in further detail.

The selected product-related services were as follows: box repacking and customized labeling linked to the packing product lifecycle phase, shipping method linked to the distribution product lifecycle phase, and documentation report linked to the use product lifecycle phase. Table 4 contains further information on the four product-related services.

Product Lifecyle Phase	**Product-related Service**	**Description**
Packing Phase	Box Repacking	The company offers customers a selection of boxes in various dimensions and the option to select the quantity of products packed in each box.
	Customized Label	The company to label each box of products with various types of customized labels.
Distribution Phase	Shipping Method	The company offers to ship orders as individual free-standing boxes, as boxes stacked on wooden pallets, or as packages to be picked up by customers.
Use Phase	Documentation Report	The company offers a documentation report containing data on product characteristics, test lab results, production records, etc.

Table 4 - Product-related services included in the scope of the configurator

4.1.3 Redesign of the specification process

The current specification process was analyzed to gain an understanding of the changes required to enable the use of the configurator. Based on the insights gained, the specification process was redesigned to fit the purpose and scope of the configurator. The current and redesigned specification systems are illustrated in Figure 4 and are further described below.

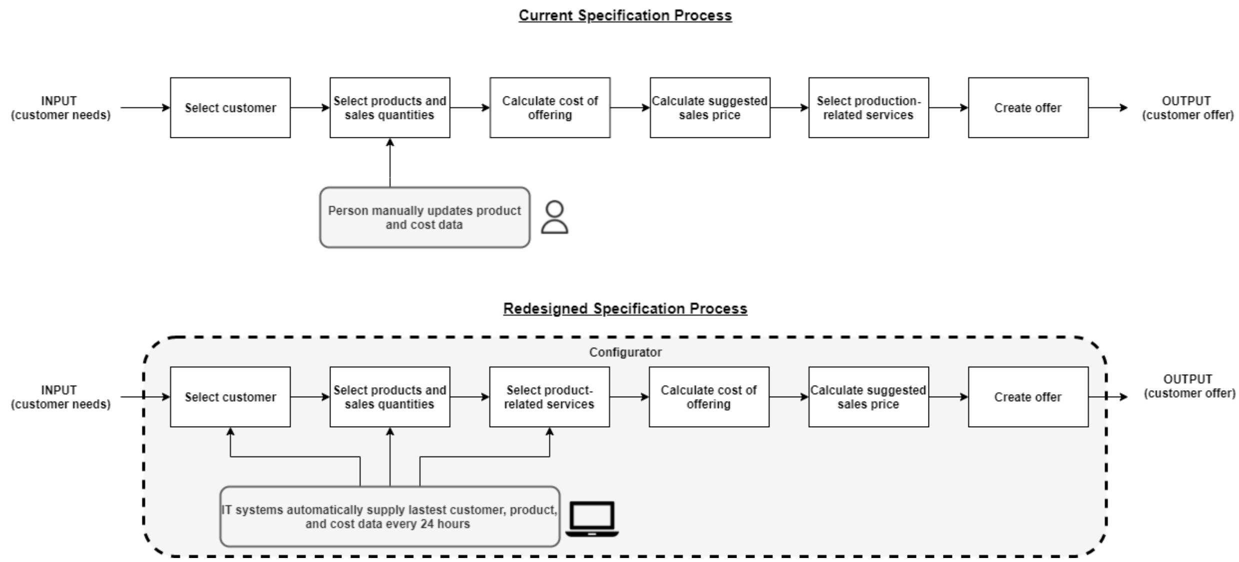

Figure 4 - Diagrams of the current and redesigned specification processes

At the beginning of the project, the specification process was conducted manually. First the customer, for whom the offering is created, was selected. However, this selection did not directly influence the solution space or costs for the remaining specification process. Then, the desired product and sales quantities were selected, and the cost of providing the offering was calculated based on the information obtained. Then, a calculation was conducted to determine the sales price required to meet a predefined contribution margin ratio. Finally, the desired product-related services were manually selected from predefined lists, and the relevant information was integrated into a finished offer to send to the customer. The selection of product-related services happened after the sales price was determined, meaning that the costs of the selected services were not considered when determining the sales price. Furthermore, the lists of available products and product-related services were manually updated as new products were introduced or changes to the cost structure occurred. This was a labor-intensive process, and it introduced a significant risk of the system not using the newest data and offers, which could lead to inaccurate offers based on outdated data.

In the redesigned process, the selection of the target customer was to be made directly in the configurator. Thus, the selection of the customer directly influenced the solution space of the configurator. After selecting the customer and products, the product-related services should be selected directly in the configurator. The cost of providing the offering should then be calculated based on the selected customer, products, and product-related services, from which a suggested sales price should be calculated. The new configurator should be connected directly to other IT systems in the case. This way, the latest customer, product, and cost data should be extracted automatically every 24 hours, thus eliminating the need for the labor-intensive process of manually updating the system and reducing the risk of calculating offers based on outdated data.

4.2 Analysis and conceptual modeling

4.2.1 Analysis and modeling of product-related services

The next step was to create a comprehensive overview of all service variants offered by the case company within each of the four product-related services in the scope of the configuration. Furthermore, decisions were made regarding how to define and select the specific service variants to be considered as *standard offerings* and included as options in the configurator. Finally, each product-related service to be included was structured in a modular manner that was appropriate for a configurator.

Workshops were conducted with relevant domain experts for each of the four product-related services. At these workshops, all existing service variants were mapped, documented, and modularized. Then discussions were held to define which service variants to include in the configurator, after which the attributes required to describe the characteristics of these variants were identified. Thus, for example, for the box repacking service, a list of all 28 existing box variants was created. After presenting and discussing the list, a total of 11 different box variants was included in the scope of the product-related services, meaning that the remaining 17 box variants would not be included as options in the configurator. Apart from selecting the desired box variant, the user of the configurator would also be required to enter the desired quantity of product units to be packed in each box. A similar process was undertaken for the customized labeling service wherein a list of 15 existing label variants was reduced to only three variants to be included as options in the configurator.

For the documentation report service, the process of listing all existing service variants was more complicated. The process of producing and delivering documentation reports was poorly structured and formalized, meaning that the creation of each documentation report was, to a large extent, treated as a unique project every time a new report was required. Therefore, a project was launched to thoroughly analyze the process of creating a documentation report. The purpose of this analysis was to structure the service into well-defined modules that make up the finished service offering. Thus, it was possible to define three distinct modules comprising the finished service offering. First, the *documentation report type* dictates the contents of the report in terms of which types of documents should be included. Second, the *report form* dictates the format in which the documentation report should be created and delivered. Various templates exist and it is also possible for the customer to have the documents manually uploaded to their IT systems. Third, the *report frequency* dictates how often a new documentation report should be created and delivered to the customer. At a workshop, it was decided that the documentation report service should consist of these three modules, each with three distinct variants to be included in the configurator.

For the shipping service, three different shipping methods existed: shipping items in individual free-standing boxes, shipping items in boxes stacked on pallets, or dispatching items in packages to be picked up by customers at the site of the case company. Generally, if the order volume is high, then it will be most cost-efficient to ship items in boxes stacked on pallets. However, as the order volume decreases, it eventually becomes cheaper to ship the items in individual free-standing boxes, as it will no longer be possible to fill an entire pallet. The specific volume of products representing the point at which it will become more cost-efficient to ship in individual free-standing boxes depends both on the dimensions of the selected product and on the customer's location. As the configurator can calculate this, it was decided to add a fourth *flexible* shipping method that would automatically select the most cost-efficient shipping method depending on the combination of the selected products and customer. However, as some customers specifically require their items to be shipped in either free-standing boxes or on pallets, it will still be possible to select these as shipping methods in the configurator. Additionally, if a customer wishes to pick-up their orders at the site of the case company, then they can either be responsible for booking this logistics service themselves or they can have the case company be responsible for the booking. This option is added as a separate module to the service. Lastly, some customers pay an additional fee for the pallets that are shipped to them. This is defined as an additional service module, but it is not relevant if the shipping method is *free-standing boxes*.

4.2.2 Definition of constraints

Workshops were conducted with relevant domain experts within the case company. At these workshops, each product-related service was analyzed, and the attendees decided how specific customer, product and service attributes should limit the solution space of the product-related services in the configurator. The purpose of the constraints was either to ensure that impossible combinations of customers, products, and service choices were made impossible to select in the configurator or to ensure that specific service variants would be impossible to offer to certain customers for strategic reasons defined by company managers. Each constraint was expressed as pseudo code to ensure the easy programming of the configurator.

Different types of constraints were formulated. First, constraints were formulated to restrict specified groups of customers from certain services. For instance, customers in certain countries were restricted to *customer pick-up* as the *shipping method*, while customers in certain customer segments were restricted to *standard* as the *documentation report form*. These constraints are respectively expressed as:

IF Customer(*Country*) = Country C **OR** Country F **THEN** ShippingMethod = *Customer Pick-Up*,

IF Customer(*Segment*) = Segment A **OR** Segment C **THEN** ReportForm = *Standard*.

Second, constraints were formulated to restrict specific product groups from certain services. For instance, certain product families were restricted to being packed in specified box types due to spatial limitations. These are expressed as:

IF ProductID(*ProductFamily)* = Product Family D **THEN** BoxVariant <> *Box Type K* **OR** *Box Type J*.

Third, constraints were formulated to restrict specific service variants from certain other service variants. For instance, if *free-standing boxes* was selected as the *shipping method,* then it should not be possible to select the *separate pallet payment* module, and if *customer pick-up* was selected as the *shipping method*, then it should not be possible to select the *booking responsibility* module. These are respectively expressed as:

IF ShippingMethod =*FreeStandingBoxes* **THEN** PalletPayment(*Cardinality*) = 0,

IF ShippingMethod = *CustomerPickUp* **THEN** BookingResponsibility(*Cardinality*) = 0.

All constraints were gathered in a document and were evaluated and validated by relevant domain experts in the case company.

4.2.3 Development of cost models

It was decided that the output of each cost model should be expressed as the *service cost per unit of product sold*. Thus, the configurator should calculate the total cost per unit for the entire offering by summing the result of each cost model.

In Section 4.2.1 each product-related service was modeled according to a modular architecture, and the specific service variants to be included in the configurator were defined. A project was initiated to collect and record the data required to calculate the cost for each service variant. These included data on the costs of shipping boxes and pallets to the location of each customer, repacking products into different types of boxes, and creating documentation reports of various types. These data were defined as attributes of the service variants and then imported into and used in the cost models of the configurator.

For each product-related service, workshops were conducted with relevant domain experts. At these workshops, the cost structures of the product-related services were analyzed, and the relevant cost drivers were identified. Cost models were then designed to calculate the cost of each product-related service according to the identified cost drivers and the attributes of the service variants. For three of the product-related services, several iterations were required before sufficiently accurate cost models were designed.

Furthermore, during these iterations, the need for additional cost data was identified, and projects were launched to collect and record this data. The following sections present the cost models that were developed.

Box repacking and custom labeling

The costs of *box repacking* and *labelling* represent a fixed cost per box. These fixed costs vary depending on the type of box or label. Therefore, the cost driver of these product-related services is the quantity of products per box. The cost models simply divide the cost per box or label with the quantity of products packed in each box. In this way, each output is expressed as the product-related service cost per unit of product sold, which is expressed in the following equations:

$$Box\ Repacking\ Cost\ per\ Unit = \frac{BoxType(\text{CostPerBox})}{Quantity\ per\ Box},$$

$$Custom\ Labelling\ Cost\ per\ Unit = \frac{LabelType(\text{CostPerLabel})}{Quantity\ per\ Box}.$$

Shipping

The cost of the shipping product-related service mainly consists of a fixed cost paid to a shipping partner for transporting a pallet or a box to a desired location. Therefore, there are two relevant cost drivers: the number of product units in each shipment and the geographical location of the customers.

The shipping product-related service consists of a main module (*shipping method*) and two sub-modules (*separate pallet payment* and *booking cost*). The cost of each module is calculated separately and summed up to obtain the total shipping cost for the order. Finally, this total shipping cost is divided by the number of product units per shipment, from which the total shipping cost per unit is calculated.

The *shipping method* module consists of two separate costs: the price paid to the shipping partner and the cost of picking and packing the order in the warehouse. These costs vary depending on the selected shipping method variant and the geographical location of a customer. If either *free-standing boxes* or *boxes on pallets* is selected as the shipping method, then the shipping and handling cost for a single pallet or box is found in two separate cost tables by looking at the rows corresponding to the country and city of the selected customer's location. The shipping and handling cost per order is obtained by converting product quantity per shipment into the number of boxes or pallets per shipment and then multiplying this by the costs found in the cost tables. If *flexible* is selected as the shipping method, the configurator automatically selects the shipping method with the lowest cost. If *customer pick-up* is selected as the shipping method, then the customers pay for the shipping cost themselves, but a fixed handling cost is added to cover the cost of picking and packing the order in the warehouse. This process is illustrated in Figure 5.

AttributeTable_ShippingMethod			
Shipping Variant	**Shipping Cost per Order [€]**	**Handling Cost per Order [€]**	**Total Shipping Cost per Order [€]**
Free-Standing Boxes	RoundUp(ProductID(OrderQuantity) / ProductID(Units/Box)) * Handling_Cost_per_Box{*Customer*(*Country; City*)} **in** CostTable_ShippingMethod(*FreeStandingBoxes*)	RoundUp(ProductID(OrderQuantity) / ProductID(Units/Box)) * Handling_Cost_per_Box{*Customer*(*Country; City*)} **in** CostTable_ShippingMethod(*FreeStandingBoxes*)	**SUM**(Shipping_Cost_per_Order{*FreeStandingBoxes*}; Handling_Cost_per_Order{*FreeStandingBoxes*})
Boxes on Pallets	RoundUp(ProductID(OrderQuantity) / ProductID(Units/Pallet)) * Shipping_Cost_per_Pallet{*Customer*(*Country; City*)} **in** CostTable_ShippingMethod(*BoxesOnPallets*)	RoundUp(ProductID(OrderQuantity) / ProductID(Units/Pallet)) * Handling_Cost_per_Pallet{*Customer*(*Country; City*)} **in** CostTable_ShippingMethod(*BoxesOnPallets*)	**SUM**(Shipping_Cost_per_Order{*BoxesOnPallets*}; Handling_Cost_per_Order{*BoxesOnPallets*})
Flexible	N/A	N/A	**MIN**(Total_Cost_per_Order{*FreeStandingBoxes*}; Total_Cost_per_Order{*BoxesOnPallets*})
Customer Pick-up	0	0,5 * Boxes_Per_Order	Handling_Cost_per_Order(*CustomerPick-up*)

CostTable_ShippingMethod(*BoxesOnPallets*)			
CustomerID(*Country*)	**CustomerID(*City*)**	**Shipment Cost per Pallet [€]**	**Handing Cost per Pallet [€]**
Country A	City A	10	1,5
Country A	City H	12	2,5
Country B	City L	16	2,5
Country C	City O	12	2,5
Country D	City N	14	1,5
Country E	City B	20	1,5
Country F	City I	22	1,5
Country G	City G	14	3,0
Country H	City F	14	1,5
Country H	City H	20	2,5
...	...	...	...

CostTable_ShippingMethod(*FreeStandingBoxes*)			
CustomerID(*Country*)	**CustomerID(*City*)**	**Shipment Cost per Box [€]**	**Handing Cost per Box [€]**
Country A	City A	1,5	0,5
Country A	City H	1,0	1,0
Country B	City L	2,5	1,0
Country C	City O	2,0	1,0
Country D	City N	2,0	1,5
Country E	City B	2,5	1,0
Country F	City I	1,0	1,0
Country G	City G	1,5	1,5
Country H	City F	1,5	0,5
Country H	City H	2,5	1,5
...	...	...	...

Figure 5 - Calculating the shipping method cost per order based on shipping variant and customer location

The cost of the *separate pallet payment* module consists of a fixed cost addition per pallet in the order. It is calculated by converting the product order quantity into the number of required pallets per shipment, rounding up to the closest whole number, and then multiplying this by the cost per pallet. This is expressed in the following equation:

$$Pallet\ Payment\ Cost\ per\ Order$$
$$= RoundUp\left(\frac{ProductID(OrderQuantity)}{ProductID(UnitsPerPallet)}\right) * PalletPayment(CostPerPallet).$$

The *booking cost* is simply calculated by adding a fixed cost per order to cover the cost of booking the transport.

Having calculated the cost for each of the three separate modules expressed as the service cost per order, the final step is to convert this into the total shipping cost per unit of product sold. This is done by summing the cost of each module and dividing this by the product order quantity per order. This is expressed in the following equation:

$$Total\ Shipping\ Cost\ per\ Unit$$
$$= \frac{Shipping\ Method\ Cost\ per\ Order + Pallet\ Payment\ Cost\ per\ Order + Booking\ Cost\ per\ Order}{ProductID(OrderQuantity)}.$$

Documentation report

The *documentation report* product-related service consists of a fixed cost per documentation report. The cost of this report depends on the service variants selected in the modules that make up the product-related service. The cost of the documentation report does not vary according to the number of product units sold. Instead, the main cost driver is the total number of product units sold per year, which means that the cost of the documentation report is to be divided between each of these products. In other words, the relative percentage of the total cost of an offer, which is represented by the cost of the documentation report, varies significantly according to the number of product units sold. If only a few product units are sold in a year, then the cost of documentation report service per product unit will be much higher than if many products are sold.

The *documentation report* service consists of a main module (*report type)* and two sub-modules (*report form* and *report frequency*). The *report type* module and the *report form* module each consists of three separate service variants representing the cost of creating a documentation report. The *report frequency* module specifies the number of reports to be created each year.

The cost model first calculates the cost of each documentation report by summing the cost of the *report type* and *report form*. It then multiplies the cost of a documentation report by the number of reports to be created per year (specified by the *report frequency* module) to obtain the total cost per year. Finally, the total cost per year is divided by the average annual product sales quantity to determine the cost of the documentation report service expressed as the service cost per product unit. This is expressed in the following equation:

$$Documentation\ Report\ Cost\ per\ Unit$$
$$= \frac{\big(ReportType(CostperReport) + Reportfrom(CostPerReport)\big) * ReportFrequency(ReportsPerYear)}{ProductID(AverageAnnualSalesQuantity)}.$$

4.2.4 Creation of an analysis model

It was decided to use PVM as the modeling technique for the analysis model. The results of the previous steps were all gathered into this analysis model, including data on more than 6700 customers and 2800 product variants, along with the nine modules comprising the architectures of the four product-related services. All possible customer, product, and service variants were described by attributes in the related attributes tables. Additionally, the cost of handling and shipping boxes and pallets to all existing locations were presented in cost tables. The analysis model also contains the constraints defined in Section 4.2.2 and the cost models developed in Section 4.2.3. The finished analysis model is shown in Figure 6. Due to confidentiality concerns, the details are not shown. A total of 14.254 unique configurations of product-related services exists based on the defined modules, service variants, and constraints. These can be combined with the selection of more than 6700 customers and 2800 product variants.

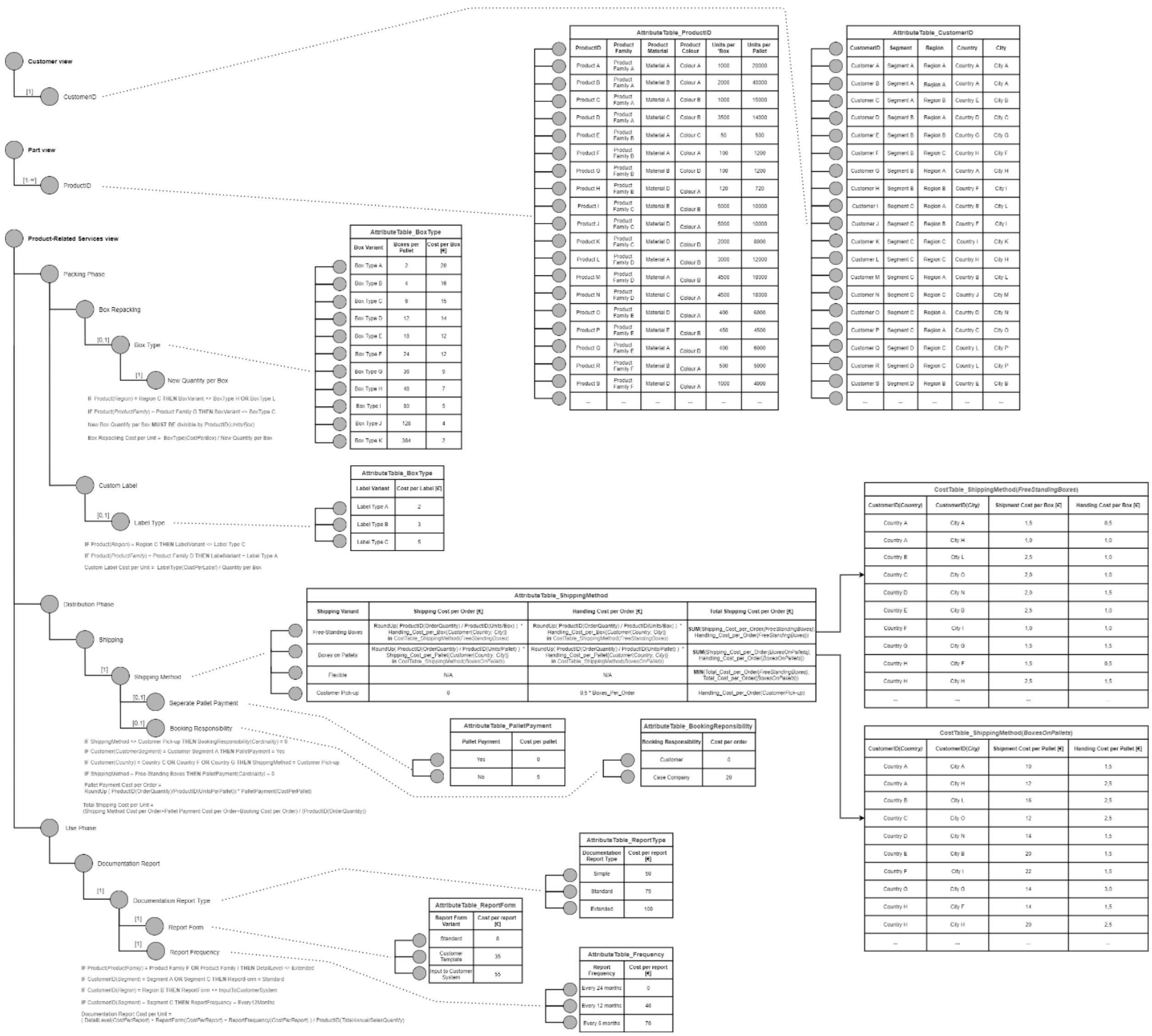

Figure 6 - Analysis model created during the case study

4.3 Design

4.3.1 Selection of configuration software

During the time in which the case study was being observed, the company was unsure of the potential value of a configurator; therefore, there was a decision not to invest in a specialized configuration software shell. Instead, Microsoft Excel was selected as the software for creating the configurator. Nevertheless, the case company expressed an interest in purchasing a dedicated configuration software shell should the configurator provide sufficient value after the study.

4.3.2 Design of user interfaces

Various mock-ups of potential designs for user interfaces were made, along with flowcharts illustrating different methods of navigating between interfaces. These ideas were presented and discussed at the workshops with selected end-users of the configurator. Based on these workshops, decisions were made regarding appropriate user interfaces. The final decision regarding the design of navigation in the configurator and the recommended navigation flow are illustrated in Figure 7. However, it was decided that users should be able to go back to previous interfaces at any time to alter their selection and, thereby, the resulting configuration.

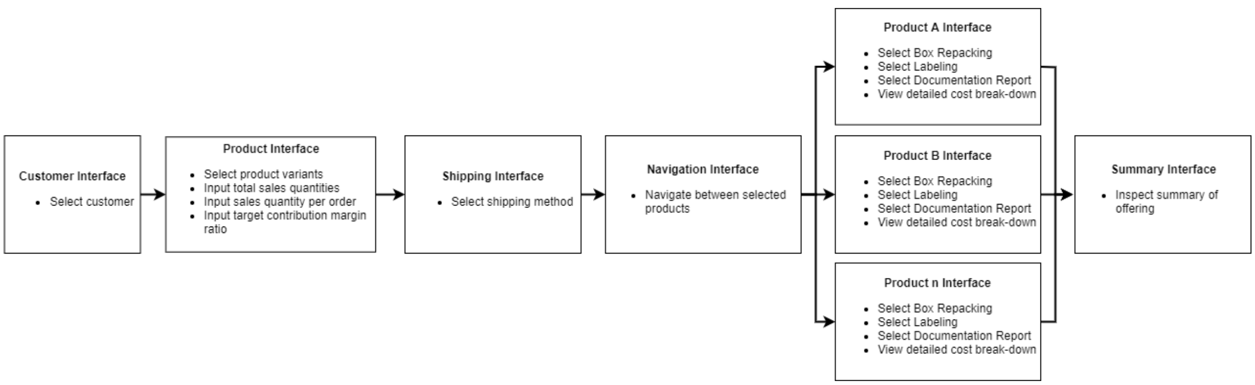

Figure 7 - User interfaces of the configurator

Additionally, several automatic prompts were incorporated into the configurator. The configurator calculates the extent to which a share of each pallet shipped will be empty. If a significant share of each pallet is empty and the freight cost is high, the system will prompt the user to inform them that significant savings can be made by increasing the product unit quantity per order or by offering an alternative shipping method. Additionally, the system calculates the cost of all available shipping methods and informs the user if more cost-efficient options exist. This information can be presented to customers who might be willing to change their shipping method or order quantity to receive a lower sales price.

Furthermore, as the cost of the *documentation report* service is not related to the number of product units sold, the cost of this service becomes very high for products with low total sales quantities. If the cost of the *documentation report* service takes up a significant fraction of the total cost of the offering, then the user is notified. This can then be communicated to customers, who will be informed of the option to select a less costly documentation report variant or to increase the total sales quantity to reduce the relative cost of the service.

4.4 Deployment

4.4.1 Programming the configuration software

The configurator was programmed in Microsoft Excel based on the contents of the analysis model (Section 4.2.4) and on the selected user interfaces (Section 4.3.2). Beta versions of the system were presented to selected end-users who identified bugs and provided feedback and improvement ideas. Based on their feedback, minor changes were made to the system. The configurator's final user interfaces are illustrated in Figure 8.

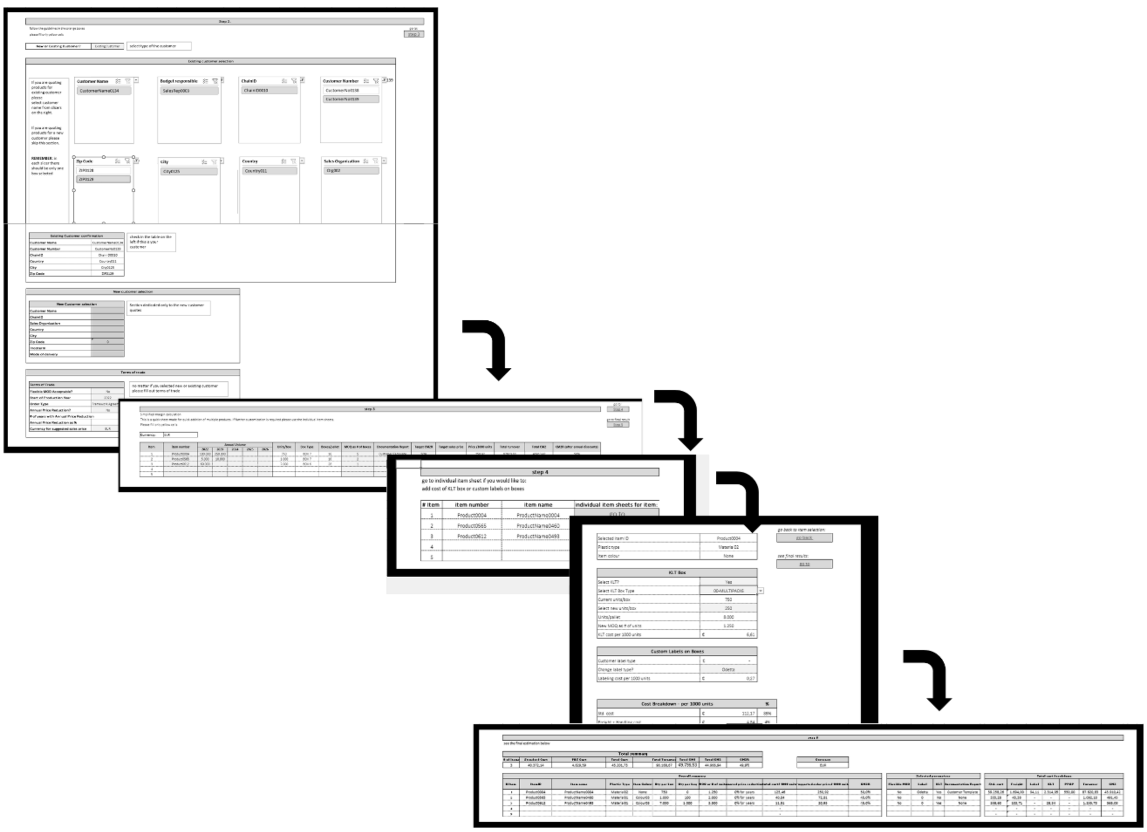

Figure 8 - Final user interfaces of the configurator

The project resulted in a configurator that can generate quotes, including several product variants and specific product-related services, for specific customers. It calculates the expected shipping costs for each product variant based on the location of the customer, the sales volume, and the product unit order quantity. It also computes the cost of alternative, more cost-efficient shipping methods and suggests these to the user. Furthermore, it calculates the cost of repacking products into boxes, marking boxes with custom labels, and creating documentation reports. Finally, either a suggested sales price is computed based on a desired target contribution margin ratio, or an expected contribution margin ratio is calculated based on a desired sales price. The details of the finalized quotes are presented in a structured manner, making it easy to send offers to customers and record the data in the IT systems of the case company.

4.4.2 Implementation of the configurator

During the next step, the broader group of users was trained in how to use the system, after which the system was officially launched. The end-users were encouraged to issue support tickets if any issues were encountered. Based on these support tickets, several minor issues were addressed.

4.5 Operation, maintenance, and further development

Previously, the list of available products to choose from when creating quotes was manually updated when new products were launched or when changes to the cost structure occurred. However, this was a time-consuming process that was also vulnerable to errors. After launching, the configurator was linked directly to the ERP system of the case company and then automatically updated with up-to-date data every 24 hours. This eliminated the need for the time-consuming process of manually updating data and reduced the risk of human errors, which could lead to incorrect data in the system.

If any major changes occur in the cost structure of the product-related services in the system or when new variants are added or removed, then both the analysis model and the configurator should be updated to reflect these changes. Similarly, if the case company wishes to include additional product-related services in the configurator, these should be added as separate modules under the related product lifecycle phases. Furthermore, service modules should be defined, constraints and cost models should be formulated, the analysis model should be extended, and the new service should be added to the configuration software.

4.6 Evaluation of the configurator

After implementing the new configurator, four main types of benefits were identified in the case company, as shown in Table 5. Some of these are discussed in this section.

Benefit	Description
Increased cost transparency	The configurator allows the user to see the potential impacts of different product-related service variants on the total cost of a quote (e.g., the cost difference resulting from different shipping methods). The new configurator considered an additional 14.5% of total costs compared with the old specification process, which only considered direct product costs.
Increase service price accuracy	The most significant value from the increased cost transparency is gained in the more extreme quotes, wherein the cost of the product-related services equals either much more or much less than 14.5% of the costs. If 14.5% of the costs for these services are simply evenly spread between all quotes, this will lead to cases wherein quotes are either significantly over- or underpriced.
Improved customer differentiation	In the first step of the new specification process, the specific customer for whom the quote is made is selected, enabling the system to differentiate between which service variants should be offered to different customers (e.g., some shipping methods might not be available to customers located in specific countries). It is also possible to require different contribution margins, depending on customer segments. These constraints can be defined in the configurator and then automatically applied when creating quotes.
More formalized and structured service specifications	The output of the configurator is a formalized and structured quote containing information regarding product variants, total sales quantities, minimum order quantities, and product-related service variants. Such data can be easily registered in an ERP or CRM system, enabling the company to follow up in the future. By summarizing the results of all quotes, users can decide whether they are willing to have low or even negative profitability on some products in the quote, and in return, make a larger profit on others, resulting in a net gain positive profit.

Table 5 - Benefits of the product-related service configurator

As described in Table 5, the configurator can more accurately calculate the expected costs of an entire quote—an additional 14.5% of total costs compared with the old specification process, which only considered direct product costs. An example from the case study is shown in Table 6. In this situation, 28 boxes of a certain type can fit on a single pallet. If a quote is created for a specific product packed in this box type and the order quantity is set to be only one box, then the shipping cost will be equal to 142% of the direct product costs. The new configurator will calculate the sales price based on this cost. However, in an average order for a customer that pays for shipping, the shipping cost equals approximately 15% of product cost. Using the old specification process, this flat rate would be added, and the sales price would instead be calculated based on this rate. If the sales price was calculated based on this cost to hit a target contribution margin ratio of 50%, then the actual margin would instead be –5.2% because the shipping costs are actually much higher. Therefore, the company would risk accepting this quote, assuming that it is profitable, but it would lose money on the quote. The opposite case is also possible. If a customer accepts an order quantity of 28 boxes instead, meaning a full pallet, then the old system would overestimate the shipping cost and calculate a sales price based on this information. However, this sales price might not be competitive, and the quote might be lost. In comparison, the new system can accurately calculate the cost savings from the higher order quantity and calculate a more competitive sales price that could still be profitable for the company.

Specification process	**Calculated shipping cost**	**Percentage of product cost**	**Total cost**	**Suggested sales price**	**Actual Contribution Margin Ratio**
Product-related service configurator	€ 9.00	142%	€ 15.34	€ 30.68	50.0%
Manual specification process	€ 0.95	15%	€ 7.29	€ 14.58	–5.2%

Table 6 - Example of the impact of shipping cost on contribution margin ratios in the new and old configurators.

Another example concerns the cost of documentation reports. The cost of making a documentation report is fixed and is therefore not tied to the sales quantity of the product. This means that if a customer purchases only a low quantity of a product, the relative cost of the documentation report is larger than if the customer purchases a higher quantity. An actual example of this is explained in the following and shown in Table 7: If a customer purchases 100,000 units of a specific product variant, the cost of the documentation report would be equal to approximately 30,3% of the direct product costs. However, if the customer instead purchases 1,000,000 units, the cost of the documentation report would only be 4.2% of the direct production costs. The new system can account for this link between the sales quantity and the cost of the documentation report to ensure that a suitable sales price is calculated.

Annual sales quantity	**Direct Product Cost**	**Cost of documentation report**	**Total cost**	**Cost of Documentation Report as % of total cost**
100,000	€ 634.00	€ 275.00	€ 909.00	30.3%
1,000,000	€ 6,340.00	€ 275.00	€ 6,615.00	4.2%

Table 7 - Example of the impact of sales quantity on documentation report costs

5 Discussion and conclusion

This article proposed an approach for the development and implementation of configurators for product-related services and tested its usefulness in an industrial setting. The tests showed that the configurator improved service cost transparency, improved service pricing accuracy, increased opportunities for differentiation of services according to customer groups and provided more formalized and structured service specifications.

The proposed approach extends the configuration literature on approaches to configurator development (e.g., Haug, Hvam, and Mortensen 2012; Hvam et al. 2019; Hvam, Mortensen, and Riis 2008; Forza and Salvador 2006; Mueller et al. 2022) by proposing a new approach that targets product-related services. As argued in the literature discussion and as demonstrated by the case study, product-related service configurators have special characteristics, rendering existing approaches for configurator development inadequate. Specifically, it addresses the need to identify existing product-related services and to systematically evaluate each service to determine which ones to include in the scope of the configurator. Additionally, it meets the need to define the necessary constraints to limit the solution space of the configurator and to develop customized service cost models based on the characteristics of the selected customers and products. For practitioners, the proposed approach offers a step-by-step tool for developing configurators for product-related services. The case also demonstrates that significant benefits can be achieved by following this approach.

However, the main limitation of the present study is that we only tested the configurator in one case company, which limits the generalizability of the usefulness of the application. However, considering that the proposed approach provides guidelines that can easily be followed by other companies, it is expected that the benefits of this approach can be generalized. Companies selling physical products as their main offerings and also offer product-related services of a certain complexity are expected to achieve significant benefits from applying the proposed approach. Nevertheless, despite showing significant potential, it should still be tested using more case companies.

Declaration of Competing Interests

The authors declare that they have no known competing financial interests or personal relationship that could have appeared to influence the work reported in this paper.

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Study D

Paper title	On-time delivery performance: Motivations for including customer requested date as comparison date
Authors	Tobias Kondrup Andersen, Lars Hvam, Cipriano Forza
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On-time delivery performance: Motivations for also considering customer-requested date as comparison date

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On-time delivery performance: Motivations for including customer-requested date as comparison date

When quantifying on-time delivery performance, the date of delivery may be compared with different expected dates. We distinguish between supplier-confirmed on-time delivery (SC-OTD) performance, which uses the supplier's confirmed delivery date as the comparison date, and customer-perceived on-time delivery (CP-OTD) performance, which uses the customer's requested delivery date as the comparison date. Through a systematic literature review, we identified different ways CP-OTD has been defined and used. Subsequently, we studied a manufacturing company to deepen our understanding of the benefits of using CP-OTD to measure delivery performance by quantifying both the SC-OTD and CP-OTD on the same set of order data from a 12-month period. Significant differences existed across various delivery time windows that were unevenly split between customer types. This indicates that quantifying CP-OTD can assist companies in identifying specific areas of their business in which significant improvement potential exists. When presented with the findings, the managers at the case company identified several opportunities for economic gain, including collecting the delivery date sensitivity of individual customers, performing analyses to map the delivery needs of specific under-serviced customer segments and identifying key customers who receive acceptable delivery service when measured using the SC-OTD but poor service when measured using the CP-OTD.

Keywords: On-time delivery, delivery performance, customer-perceived on-time delivery, supplier-confirmed on-time delivery, delivery reliability

1. Introduction

High-performing supply chains are crucial to the competitiveness of manufacturing companies. Manufacturing companies compete on various performance measures, such as quality, flexibility, delivery and costs (Sarmiento et al. 2007). In recent years, new challenges associated with the COVID-19 pandemic and subsequent recovery have been hindering some companies from meeting acceptable levels of delivery performance. Disturbances caused by the war in Ukraine have added additional barriers to meeting delivery performance goals, especially in Europe. As a result, the importance of managing delivery performance has increased, which indicates the need for appropriate measurement tools.

Measuring delivery performance, however, is a complex task because multiple aspects must be considered; this is exemplified in the different ways scholars have defined delivery performance. Ulaga and Eggert (2006), for example, identified three main dimensions of delivery performance: (1) on-time delivery, which is the ability of a supplier to consistently meet delivery schedules; (2) delivery flexibility, which is the ability to adjust to changes in delivery schedules because of spikes in demand or changes in the product mix; and (3) delivery accuracy, which is the ability to deliver the correct parts and to do so consistently. Peng and Lu (2017) divided delivery performance into two main dimensions – reliability and speed – which they further categorised into on-time delivery rate, early delivery inaccuracy, late delivery inaccuracy and delivery speed.

The current article describes our investigation into the various ways to measure on-time delivery (OTD), by which we mean the percentage of orders delivered on time. To quantify OTD, the time of delivery is compared with what Forslund and Jonsson (2007) referred to as a *comparison date*. The definition of the comparison date can vary: for instance, it can be the date agreed upon and confirmed by the supplier, or it can be the date originally requested by the customer. Using the supplier-confirmed delivery date to quantify OTD provides a measure of how well a supplier manages to deliver on what it has promised, while using the customer's requested delivery date evaluates how well a supplier can comply with the temporal needs of its customers (Forslund and Jonsson 2010; Knoblich, Heavey, and Williams 2015).

In this article, we define OTD by using the supplier-confirmed delivery date as the comparison date to produce what hereafter is referred to as the supplier-confirmed on-time delivery (SC-OTD) rate. When using the customer's requested delivery date, we define OTD as the customer-perceived on-time delivery (CP-OTD) rate: we introduce the word ‘perceived’ because this indicator recalls the judgemental comparison that customers consciously or unconsciously make between their temporal need (expressed through their order request) and how well it has been satisfied.

The literature has investigated numerous benefits to be gained from improving OTD performance, including reduced likelihood of returns (Rao, Rabinovich, and Raju 2014), ability to charge higher prices (Mewborn, Murphy, and Williams 2014), increased transaction quantity and unit price (Peng and Lu 2017) and supplying a leading indicator for future sales (Nagar and Rajan 2001). Thus, OTD is a significant driver of improvement initiatives within a company. Coronado et al. (2017) found, for example, that OTD is among the most important factors affecting manufacturing technology selection within UK composite material supply chains. Furthermore, the literature indicates that a responsive planning and control system is the most important facilitator of good delivery performance (Lane and Szwejczewski 2000) and that companies can positively influence the OTD of their key suppliers through socialisation efforts (Cadden et al. 2020).

However, efforts to improve both CP-OTD and SC-OTD rates are costly, and resources tend to be limited, so companies must understand the optimal methods and areas in which to improve these rates to make appropriate improvement decisions. Such decisions require measurements of both the CP-OTD and SC-OTD. Nevertheless, the CP-OTD has received limited attention in academic research, despite the need to measure it appropriately to clearly understand the benefits provided by doing so. Accordingly, based on this knowledge need, the present article is designed to answer the following research questions:

- *How is the customer-perceived on-time delivery rate used, and what benefits can be realised by measuring the customer-perceived on-time delivery rate?*

To answer these research questions, this article is structured as follows. First, we describe the systematic review we conducted to identify the ways CP-OTD has been defined and used in the literature. Next, we present a case study involving a Danish manufacturing company that examines how CP-OTD can be added to SC-OTD to measure OTD performance and to assess its adequacy in satisfying different customers to identify improvement opportunities. To do this, the same set of delivery order data was used for both measures, and the results obtained were assessed by company managers. Based on the findings, we provide reflections on how the CP-OTD can be used and the insights that can be gained from quantifying both the CP-OTD and SC-OTD. These reflections can help companies determine how to improve delivery performance by improving their measures of OTD.

Overall, we practically and theoretically exploit potential implications indicated by Forslund and Jonsson (2007) regarding the measurement of OTD performance that, until now, have not been recognised in the relevant literature.

2. Literature review

2.1. Execution modalities

We started our enquiry by setting the stage for the consideration of CP-OTD within the OTD literature. More specifically, we performed a systematic literature review, first identifying how OTD has been defined (regarding the use of different comparison dates) and subsequently focusing on how the CP-OTD rate has been used as a performance measure. A systematic literature review involves three phases: planning, conducting and reporting (Tranfield, Denyer, and Smart 2003).

During the planning phase for the current study, we developed a search string that included various keywords and synonyms for OTD; the search string was designed to limit the results to only articles that addressed OTD in the production, manufacturing or operational contexts. We selected both Scopus and Web of Science as literature databases but excluded book chapters and conference papers because of the lack of a peer-review process. The search strings used for each of the two databases are shown in Table 1. The search was limited to journal papers published after 1995 and written in English. The article data, including title, author name(s), publication name, publication year, key words and abstract, were extracted from the databases and further processed in a spreadsheet. The final extract was made on October 26, 2021.

Table 1 - Search strings

Database	**Search string**
Scopus	TITLE-ABS-KEY (“on time delivery” OR “delivery performance” OR “delivery reliability” OR “delivery timeliness” OR “order timeliness”) AND TITLE-ABS (“production” OR “manufactur*” OR “operation*”) AND PUBYEAR > 1996 AND (LIMIT-TO (SRCTYPE , “j”)) AND (LIMIT-TO (LANGUAGE , “English”))
Web of Science	(TS=(“on time delivery” OR “delivery performance” OR “delivery reliability” OR “delivery timeliness” OR “order timeliness”) AND TS=(“production” OR “manufactur*” OR “operation*”)) Additional filters: LANGUAGE: (English) AND DOCUMENT TYPES: (Article) AND [excluding] DOCUMENT TYPES: (PROCEEDINGS PAPERS), Timespan: 1996–2021

Following the initial extract, journal quality criteria were applied to the sample of journal articles to narrow the literature selection and identify studies of the highest quality. To be included, a journal had to have ranked in the first or second quartile of the Scimago Index in 2020 within the subject areas of business management and accounting, engineering, decision science or economics, econometrics and finance. Furthermore, duplicate articles were removed.

Abstract criteria were then applied to identify articles that addressed quantifying OTD, involved a survey regarding OTD and/or discussed the definition of OTD. Further, only articles that pertained to manufacturing companies were included. Finally, articles that referred to studies of the OTD of internal production orders were removed, thus leaving only articles related to customer delivery orders. If qualification according to the abstract criteria could not be clearly determined, the article was included for full-text reading.

Full-text reading was performed to confirm that each article met the criteria of addressing the OTD of customer delivery orders in a manufacturing setting. The full-text reading resulted in a final sample of 182 articles, which were then analysed through a meta-synthesis, a technique for thematically analysing and synthesising the literature (Tranfield, Denyer, and Smart 2003). Key variables were coded, including research methodology, definition of OTD, comparison date used and the perspective (buyer or supplier) from which the study was performed.

The results of the article screening are illustrated in Figure 1, where the initial sample of 1,411 articles was reduced to 182 articles marked for in-depth analysis.

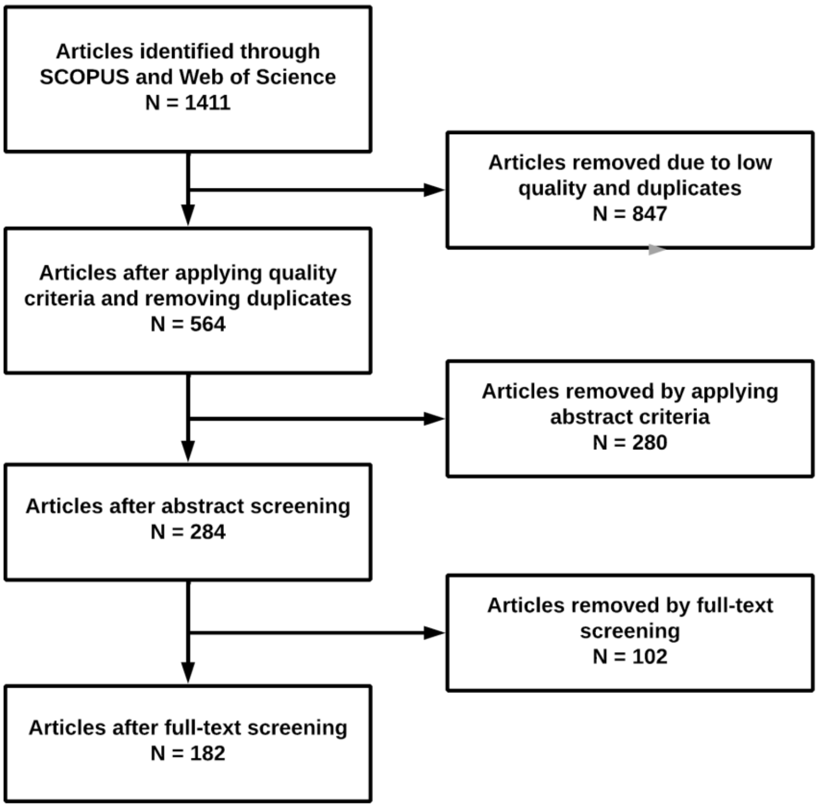


Figure 1 - Article selection process

2.2. Literature review results

2.2.1. General description of the identified articles

The remaining articles were quite dispersed across various journals. However, more than half were published in the following 10 journals that can be considered the core area for the OTD discussion: *International Journal of Production Economics* (23), *International Journal of Production Research* (21), *International Journal of Operations and Production Management* (10), *European Journal of Operational Research* (9), *Journal of Manufacturing Technology Management* (7), *Production and Operations Management* (7), *Journal of Operations Management* (5), *International Journal of Advanced Manufacturing Technology* (4), *Journal of Supply Chain Management* (4) and *Production Planning and Control* (4).

The review revealed a prevalence of surveys (44%) with respect to the methods adopted in the research, followed by modelling papers (34%) and case studies (16%); some literature reviews (4%) and conceptual papers (2%) were also identified.

Types of raw data

Most research on OTD relies on data analysis. Consequently, the investigation capabilities of this research greatly depend on the characteristics of the raw data from which researchers start their analyses. The raw data used can be empirical or simulated. The use of empirical data allows for a complete description of the full complexity of the reality, but such data are costly to acquire and difficult to analyse. Conversely, the use of simulated data does not allow for such complete descriptions of the reality. However, much noise is removed with this approach, and the resulting analyses can be very robust. Furthermore, the raw data can be available at different levels of aggregation. For example, researchers can begin their analyses using data from each individual order line for a given period, including both the promised and actual delivery date. Access to data at the order-line level enables the researcher to be in complete control of the way that OTD is being quantified. Alternatively, researchers may only have access to OTD measures at a higher level of aggregation, such as for an entire company or for a specific supplier across all order lines. At this level of aggregation, the researchers do not have control of how OTD is quantified and also are unable to manipulate the quantification to control for contingency factors at the level of a single company (e.g. different product types or customer segments).

According to the results of the literature review, research on OTD has been performed using different types of raw data: 61% of the studies described in the selected articles were based on empirical data, 35% were based on simulated data and 4% were literature reviews that did not use any type of data. Of the studies highlighted in the sample articles, 22% involved the use of real order level or order-line level data, and 74% involved the use of raw data at a higher aggregation level, typically at the plant or company level for a given period. Obviously, access to real order level data is not easily obtained. This helps to explain why only 2% of articles referred to the use of raw empirical data aggregated at the order level and why they were all case studies. However, most of the case study articles (comprising 16% of the considered articles) did not refer to the use of order level data, even though doing so would be potentially feasible but very demanding using this research method. Table 2 provides an overview of the types of raw data used in the studies described in the selected articles.

Table 2 - Types of raw data used in studies in selected articles

Aggregation level of raw data	**Source of raw data**		
	Empirical	**Simulated**	**Total**
Order or order-line level	2%	20%	22%
Aggregation-of-orders level (e.g. plant, company)	59%	15%	74%
Total	61%	35%	96%

Contingency factors in studying OTD

In the articles under examination, some scholars consider the OTD rate as it relates to all orders (or order lines) of the company (or companies) under study, while others consider subsets of these orders based on product type, customer type or other contingency factors. More specifically, of the articles reviewed, 45 (23%) describe studies that considered contingency factors. Most of these articles (23) focus on examining the OTD of multiple suppliers from the buyer's perspective, often with the purpose of identifying the optimal supplier(s). Ten of the articles address the effects of OTD on different ways to respond to the market, including various levels of form postponement, inventory strategies or production strategies. Three articles highlight studies on the OTD of multiple customer groups, while the studies in three others focused on the OTD of multiple product types. The remaining six articles reference other aspects of contingency factors, including levels of information sharing and levels of uncertainty. The contingency factors analysed in the articles selected are shown in Table 3.

Table 3 – Contingency factors analysed in the articles selected

Contingency factors	**# of papers**	**Distribution of papers**
Suppliers	23	51%
Ways to respond to the market	10	22%
Customer groups	3	7%
Product types	3	7%
Others	6	13%

OTD is a measure of the service given to customers. Customers commonly have different levels of sensitivity to different rates of OTD. Therefore, the finding that only three articles (7%) covered studies that considered customer groups as a contingency factor is surprising. Of these three articles, only one (i.e. Peng and Lu 2017) referred to the use of real order level data. This article quantifies the impact of supplier delivery performance on future customer transaction volume and unit price using transaction-level data related to exchanges between a manufacturer of heating, ventilation and air conditioning products and its customers. The studies in the other two articles examined the impact of marketing decisions on delivery performance for different markets (Marques et al. 2014) and modelled the impact of dispatching rules on the OTD of vital and normal priority customers (Kher and Fry 2001).

2.2.2. The quantification of OTD

Forslund and Jonsson (2007) argued that four metrics are required to quantify OTD (see Table 4). The first is the *measurement object*, which is the object on which the OTD is quantified. This can be the number of orders, number of order lines, individual items or even turnover. The *time unit* defines the period during which the measurement object must be delivered for the delivery to be considered on time. This is also called the *delivery time window* and is referred to as such in the current article. This window can comprise the correct day, the correct week or a more customised time frame (e.g. +1/-2 days). The *measurement point* defines the location along the supply chain at which the measurement object is considered delivered. This can be the point at which the object is shipped from the supplier or when it is received at the customer site. The *comparison date* is the date compared to the time of delivery to determine if the measurement object was delivered on time. For example, this can be the date confirmed by and committed to by the supplier; the delivery date initially requested by the customer is another option

Table 4 - Four metrics required to quantify the on-time delivery rate (Forslund and Jonsson 2007)

Metric	**Example**
Measurement Object	Order, order line, individual items, turnover
Time Unit / Delivery Time Window	Correct day, correct week, time window
Measurement Point	When shipped from supplier, when received at customer site
Comparison Date	Supplier-confirmed delivery date, delivery date originally requested by customer

Studying multiple delivery time windows

Different customers have different sensitivities regarding OTD levels; they may attribute different meanings to OTD as well. For some, an order line that is delivered one day before the day it was promised is considered on time, while others may not consider that delivery on time. Consequently, OTD needs to be defined in relation to potentially different delivery time windows, depending on the needs of the customers. This being the case, we can expect research efforts to explore the use of multiple delivery time windows, even within the same company. Contrary to this expectation, only five (3%) of the articles identified for our review reported on studies regarding the impact of using multiple delivery time windows. The data for the studies in two of these articles were gathered through surveys asking respondents which delivery time windows they used to quantify OTD. The remaining three articles pertained to modelling studies using simulated data. Thus, no articles were found that described studies that employed real order data to quantify OTD using multiple delivery time windows.

Comparison dates

Forslund and Jonsson (2007) recommended that the definition of OTD specify whether to consider the requested date or the confirmed date as the comparison date. Notably, the majority (59%) of the articles reviewed did not explicitly specify which comparison date definition was used (see Table 5). Of the 75 articles that did specify a comparison date definition, 61 referred to use of the supplier-confirmed delivery date, while only 14 referred to use of the customer-requested delivery date. This indicates that CP-OTD is understudied in the literature.

Table 5 - Comparison date definitions in identified articles

Comparison date definition	**Number of articles**	**% of articles**
Not specified	107	59%
Confirmed only	61	34%
Requested included	14	7%
TOTAL	182	100%

2.2.3. How CP-OTD is used in the literature

As Table 5 shows, 14 of the articles selected for the review highlighted studies in which the customer-requested delivery date was used as the comparison date. Six of those articles feature studies that used both the customer-requested and supplier-confirmed dates and, to some extent, discuss the difference.

Table 6 - Comparison dates used in CP-OTD articles

Comparison date	**Number of articles**	**% of articles**
Customer-requested	8	57%
Both customer-requested and supplier-confirmed	6	43%
TOTAL	14	100%

Table 7 presents a comparison of the 14 articles that highlight studies that used the requested date as the comparison date. According to the recommendations from Forslund and Jonsson (2007), five of the articles do not specify the measurement object being used, two do not specify the delivery time window and three do not specify the measurement point. Furthermore, only two articles refer to multiple variations of measurement objects, delivery time windows and measurement points: both were written by Forslund and Jonsson (2007, 2010). In addition, most of the articles (8) do not reference the use of multiple units of analysis within the same company, while only two articles outline studies on OTD for multiple product types, and only four for multiple suppliers. Various research methods are described in the 14 articles, namely, surveys, case studies and modelling, along with a single literature review. Moreover, seven articles refer to studies in which real raw data were used, while the use of simulated data is mentioned in six. Four articles describe the use of raw data at order level, and nine describe the use of raw data synthesised at a higher aggregation level. Only one article describes the use of real raw data at order level.

Author(s)	Research method	Measurement object	Delivery time window	Measurement point	Comparison date	Source of raw data	Aggregation level of raw data	Contingency factor
Tenhiälä, Rungtusanatham, and Miller (2018)	Survey	Not specified	One	Not specified	Requested & Confirmed	Real	Aggregation-of-orders level	None
Forslund and Jonsson (2007)	Survey	Multiple	Multiple	Multiple	Requested & Confirmed	Real	Aggregation-of-orders level	None
Forslund and Jonsson (2010)	Survey	Multiple	Multiple	Multiple	Requested & Confirmed	Real	Aggregation-of-orders level	None
Forslund and Mattsson (2021)	Survey	Not specified	Not specified	Delivery at customer site	Requested & Confirmed	Real	Aggregation-of-orders level	None
Knoblich, Heavy, and Williams (2015)	Modelling	No. of items	One	Delivery at customer site	Requested & Confirmed	Simulated	Order level	Product types
Gunasekaran, Patel, and Tirtiroglu (2001)	Literature review	Not specified	Not specified	Delivery at customer site	Requested & Confirmed	N/A	N/A	None
Sawik (2010)	Modelling	Orders	One	Shipped from supplier	Requested	Simulated	Aggregation-of-orders level	Suppliers
Choudhary, Singh, and Tiwari (2006)	Modelling	Order lines	One	Delivery at customer site	Requested	Simulated	Order level	None
Garg, Narahari, and Viswanadham (2006)	Modelling	Order lines	One	Delivery at customer site	Requested	Simulated	Order level	Suppliers
Karpak, Kumcu, and Kasuganti (1999)	Modelling	Not specified	One	Not specified	Requested	Simulated	Aggregation-of-orders level	Suppliers
Terwiesch et al. (2005)	Case study	Order lines	One	Delivery at customer site	Requested	Real	Aggregation-of-orders level	None
Heim, Peng, and Jayanthi (2014)	Case study	Order lines	One	Shipped from supplier	Requested	Real	Order level	Product types
Robertson, Gibson, and Flanagan (2002)	Case study	Not specified	One	Not specified	Requested	Real	Aggregation-of-orders level	None
Shin, Benton, and Jun (2009)	Case study	No. of items	One	Delivery at customer site	Requested	Simulated	Aggregation-of-orders level	Suppliers

Table 7- Dimensions of the 14 articles that highlight studies that used customer-requested date as comparison date

Considering the customer-requested date as the comparison date can lead to interesting insights into various OTD contingencies, especially related to different customer groups. However, of the articles featuring studies that considered CP-OTD, only two address multiple time windows, only six refer to both customer-requested and supplier-confirmed delivery dates and only one reports the use of real order level or order-line level data; none of the articles highlight studies that used different customer groups as contingency factors. This indicates that much of the potential for this kind of enquiry based on the metrics presented by Forslund and Jonsson (2007) is still unexplored.

To exploit some of the possibilities associated with this line of enquiry, we need to consider in more detail the content of the articles in which CP-OTD was considered in the research. These articles are explained in the following two subsections: the first focuses on six articles that describe studies that considered both customer-requested and supplier-confirmed delivery dates, and the second highlights the remaining eight articles in which only the customer-requested delivery date was considered in the research. Within these two groups of articles, we further organise them according to the research methods used and the topics studied. Several of the articles were written by the same authors, and these articles are presented together.

Both customer-requested and supplier-confirmed dates

As shown in Table 7, six articles were included in the review that refer to studies in which both the customer-requested and supplier-confirmed delivery dates were used as the comparison date. These articles are discussed next.

Forslund and Jonsson (2007) examined six customer/supplier dyads and found a significant lack of alignment in the metrics used to quantify OTD within each of the dyads. They noted that only one member in the six dyads studied had used the requested delivery date as the comparison date. In their later article, Forslund and Jonsson (2010) present the results of their survey of 257 Swedish manufacturing companies that asked which metrics the company used to quantify the OTD of their suppliers. They reported that only 28% of the respondents used the requested delivery date as the comparison date. This low number is surprising based on their argument that the requested delivery date would be the better choice from a customer perspective. In a more recent article, Forslund and Mattsson (2021) share the results of a survey they conducted of 224 purchasing managers at Swedish manufacturing companies to identify and characterise the measures used for supplier flexibility; they discovered that 47% of the respondents used a type of OTD reliability metric to measure supplier flexibility, indicating that companies perceive flexibility to be the same as reliability or that suppliers who are flexible are also reliable. The authors contemplate in their article what happens when a customer requests a change to an already confirmed delivery date. What is measured then: the delivery reliability or flexibility? They identify this as a grey area. They also mention the result that only 25% of the respondents who quantified delivery reliability used the customer-requested delivery date as the comparison date, mirroring the results from a previous article published 11 years prior (Forslund and Jonsson 2010).

Tenhiälä, Rungtusanatham and Miller (2018) conducted a survey of 163 production planners to explore the conditions under which stand-alone enterprise applications would be more suitable than an enterprise resource planning (ERP) system. The respondents were asked to evaluate their company’s ability to confirm deliveries for the first requested date, meaning how often they commit to meeting their customers’ initial delivery requests, although this is not a true measure of OTD because it only measures what the supplier aims to provide, not what is ultimately delivered. The respondents also evaluated their company’s ability to deliver based on their confirmed delivery date. This study involved both the requested and confirmed delivery dates, but it did not measure true CP-OTD.

Gunasekaran, Patel and Tirtiroglu (2001) conducted a literature review and developed a framework for measuring strategic-, tactical- and operational-level performance in a supply chain. In their article, they describe OTD as being used to determine whether a perfect delivery has taken place and explain that it can be measured as either 'delivery-to-request date' or as 'delivery-to-commit date'. However, they do not discuss the difference between these two measures any further.

Knoblich, Heavey and Williams (2015) evaluated the performance of different supply chain contracts that regulate the binding period within which order quantities can be changed and the quantity flexibility, meaning the upper and lower boundaries for order quantity changes. They model a semiconductor supply chain consisting of a buyer, supplier (semiconductor manufacturer) and capacity provider. The buyer provides an initial demand forecast. Adjustments to this demand forecast can be requested by the buyer, and if the change is within what is allowed by the supply chain contract, the change is confirmed. If the change is outside what is allowed by the supply chain contract, then only the extent of the change that falls within what is allowed by the supply chain contract is confirmed. The authors quantify the performance of supply chain contracts according to inventory levels and performance metrics. One metric is called *delivery performance (DP),* which is the ratio of delivered products compared with the number of products in the last demand request from the customer (even if this demand falls outside what is allowed by the contract clauses). The second metric is *delivery reliability (DR),* which is the ratio of the total number of products delivered compared with the confirmed order quantity, here, according to what is allowed in the supply chain contract. The authors argue that DP can be seen as a measure of customer satisfaction, while DR can be seen as a measure of how well supply chain contract flexibility is satisfied by the supplier (Knoblich, Heavey, and Williams 2015). This is the only article in which both CP-OTD and SC-OTD are quantified on the same set of simulated order data and their differences evaluated. However, the simulated model is specific to a semiconductor supply chain, so the results cannot be directly generalised to more generic supply chain designs. Furthermore, only simulated order data are considered rather than empirical order data. Finally, the behaviour of the supplier is entirely regulated by a supply chain contract that is agreed upon beforehand.

Only customer-requested date

As depicted in Table 7, eight articles were identified for the literature review that only mention the use of the customer-requested delivery date as the comparison date. These articles are discussed next.

Two of the articles describe case studies that investigated the impacts of various factors on OTD. Terwiesch et al. (2005) conducted a case study to understand the relationship between a buyer’s forecasting behaviour and the supplier’s OTD. The supplier’s OTD was measured using the delivery dates requested by the buyer as the comparison date. The authors concluded that buyers had an incentive to inflate their forecasts to ensure adequate capacity by the supplier, while to avoid overproduction, the supplier had an incentive to postpone production until the buyer ultimately committed to the order. The consequence was that the unreliable forecasts of the buyer directly impacted the OTD of the supplier. Heim, Peng and Jayanthi (2014) quantified OTD on a real set of 32,000 customer orders from 900 customers in a case company, exploring the impacts of demand, internal manufacturing and supply chain factors on delivery performance. They considered an order to be delivered on time if it left the shipping dock at the manufacturer’s facility on or before the customer’s requested date for the order shipment. When quantifying OTD, they clearly specified the four metrics used, as recommended by Forslund and Jonsson (2007).

Three of the articles present approaches to improving OTD rates. Robertson, Gibson and Flanagan (2002) developed a planning and scheduling model that was tested in a case study involving an international steel manufacturer, which they describe in their publication. The authors propose a set of key measures to assess the performance of the model. One measure is OTD, which they define as orders delivered in full within the customer's requested delivery time window. Choudhary, Singh and Tiwari (2006) created a probabilistic model that uses the tolerances of lead times of internal business processes in a supply chain network to compute the probability that orders will be delivered on time according to a customer-specified delivery window. Garg, Narahari and Viswanadham (2006) devised an approach to reduce variability and enhance business process synchronisation in supply chains as a way to increase OTD rates; they introduced a novel measure of OTD called *delivery sharpness,* which was inspired by an analogy between tolerances in mechanical assemblies and supply chain networks. This measure was quantified using a customer-specified delivery window as the comparison date. They then designed an approach to compute the allowable variability in lead times for the individual stages of a supply chain so that the specified levels of delivery sharpness and delivery probability can be achieved in a cost-effective way.

The final three articles discuss models for supplier selection using supplier OTD as a selection criterion. Karpak, Kumcu and Kasuganti (1999) created a model for supplier selection that minimises production costs while maximising product quality and OTD rates. The OTD rating is decided based on the percentage of orders delivered by the supplier within a delivery window specified by the buyer. Shin, Benton and Jun (2009) developed a sourcing policy decision tool to determine an optimum set of suppliers when several sourcing alternatives exist. The tool evaluates the OTD rate of orders using the delivery time specified by the buyer. Sawik (2010) proposed a model for the optimal selection of suppliers from which to purchase the custom parts required for specific customer orders in a make-to-order setting based on price, quality and OTD; in this model, OTD is defined by the late delivery rate of suppliers and is quantified using the buyer's requested delivery date.

3. Research objective

As illustrated in the review of the literature, most articles (58.8%, or 107 out of 182) do not specify the comparison date used in the research, while the CP-OTD rate is addressed in only 7.7% (14 out of 182). This result points to a dearth of research on CP-OTD in the literature, despite its significant use by companies: data on Swedish companies indicate that it is used by 25–28% of companies (Forslund and Mattsson 2021; Forslund and Jonsson 2010). Moreover, even less scholarly attention has been paid to the implications of considering both the CP-OTD and SC-OTD: only one study (Knoblich, Heavey, and Williams 2015) quantified both the CP-OTD and SC-OTD on the same set of orders and considered their differences; however, that research was based on simulated data in a specific supply chain regulated beforehand by a specific form of contract and was focused on the performance of the different contracts, not on managerial insights related to the CP-OTD and SC-OTD.

Consequently, even though the relevance of the CP-OTD evaluation is signalled by its use in practice and by the 14 articles that consider the CP-OTD in the literature, the specific value of the CP-OTD is still under investigated. In particular, empirical evidence that shows how the CP-OTD rate can be used and what value a company can receive from its use is lacking. Given that the most common measure of OTD performance seems to be the SC-OTD rate, examining CP-OTD in relation to SC-OTD seems to be the optimal way to gain insights into CP-OTD.

Furthermore, the literature on OTD in general has paid limited attention to customer groups as contingency factors (surprisingly, with no publications that document doing this using empirical order level data). A similar scarcity of research exists regarding the impact of using different delivery time windows: no papers were found that describe the use of empirical order level data. Finally, the potential for research on OTD using empirical data at the single order line level is completely untapped.

Hence, we decided to contribute to the literature in this area by empirically investigating through a case study how CP-OTD and SC-OTD can be jointly used to measure OTD and to assess OTD adequacy in satisfying different customers in order to identify improvement opportunities. This investigation contributed to exploiting the potential implications indicated by Forslund and Jonsson (2007) regarding the measurement of OTD performance that, until now, have not been recognised in the related literature.

4. Method

To contribute to the literature as intended, we quantified both the SC-OTD and CP-OTD on the same set of actual order data and, in a real context, studied the benefits that can be obtained from using both measurements. We used real empirical order data from a Danish manufacturing company with a generic supply chain design (i.e. not regulated beforehand by contract). Within this setting, the behaviour of the supplier was not influenced by a contract signed before receipt of the order request; instead, each order was evaluated individually. We followed the framework presented by Forslund and Jonsson (2007) to specify the metrics to use to quantify the OTD rate in our case study. In this way, we were able to explore in a real setting how considering market contingencies, different delivery windows and CP-OTD can enhance the power of delivery performance measurement systems to identify potential areas of improvement.

4.1. Research design

In the literature review, only a single article was identified in which both CP-OTD and SC-OTD were quantified using the same set of order line data (Knoblich, Heavey, and Williams 2015). Although the authors did explore the impact of using different delivery time windows, their analysis was based on simulated data. Basing such an analysis on real data would allow for investigating the influence of various contingencies, such as market-related factors.

Additionally, the use of real data would facilitate exploring managers' appreciation of the results obtainable by including CP-OTD metrics in the on-time delivery measurement.

To quantify the CP-OTD, a company is required to register customers' requested delivery dates for individual orders. These data must be registered for an extended period to give useful insights into CP-OTD performance. Because most companies cannot be expected to register and store these data, using a survey to gather data on the difference between CP-OTD and SC-OTD performance in companies would be difficult. Additionally, the data collected must reflect the exact criteria that we attribute to it, and this is only possible through direct – or at least very close – control of the data. This would also not be feasible through a survey.

Due to the lack of a fundamental understanding of this topic and the difficulties associated with collecting and controlling the required data, an in-depth analysis utilising empirical data was preferable to using broader, less in-depth data (Shurrab, Jonsson, and Johansson 2022). Therefore, we opted for a single-case study approach, similar to Tedaldi and Miragliotta (2022), Shurrab, Jonsson and Johansson (2022), Garengo and Betto (2022) and Ferreira Junior, Scur and Nunes (2022). A single-case study is particularly appropriate in situations like ours, when limited data are accessible and knowledge on the topic is lacking, which are limitations that call for an explorative approach (Yin 2018). Furthermore, in this case, we anticipated that the explanation and exemplifications of the results of our analyses would be easier to comprehend in the context of a single case. The study was carried out using real customer delivery order data at the single order line level from a Danish manufacturing company over a one-year period. Notably, this type of data has never been used in OTD research prior to this study. Nevertheless, we believe it offers interesting potential to explore OTD in new ways and, through these new ways, to identify factors that have not previously been considered.

4.2. Case context and scope

The company selected for the case study was a Danish manufacturer of high-quality, injection-moulded plastic products. The company employed approximately 200 workers, reported an annual turnover of 23 million euros and served customers located in more than 45 countries. The case company had established a delivery performance measurement system, but it only evaluated order lines according to the promised delivery date. Prior to this case study, the company did not keep a record of the customers' requested delivery dates for individual orders. Instead, that data field in the ERP system was overwritten with the confirmed delivery date. For the study, the process was changed so that the initially requested delivery date was recorded in a separate data field in the ERP system and could not be overwritten. The confirmed delivery date was then recorded separately.

The ordering process in the case company was as follows. A customer would submit a purchase order request detailing the product variant(s) and quantities desired, along with a customer-requested delivery date. This order was received at the case company, and the initially requested delivery date was recorded. The case company then evaluated the order request. If the request was confirmed, an order confirmation was generated and sent to the customer, and the confirmed delivery date was recorded in the ERP system. If the request was declined, an alternative order delivery date was generated and suggested to the customer, which started a loop in the process. First, the customer evaluated the alternative order delivery date suggestion, and if it was acceptable, an order confirmation was generated for the case company, and the confirmed delivery date was recorded in the ERP system. If the suggestion was declined, the order was either cancelled and the process stopped, or a modified order request was generated and sent to the case company, starting the evaluation loop again. Note, however, that the requested delivery date was only recorded in the ERP system at the first instance of the loop. This ordering process is illustrated in Figure 2.

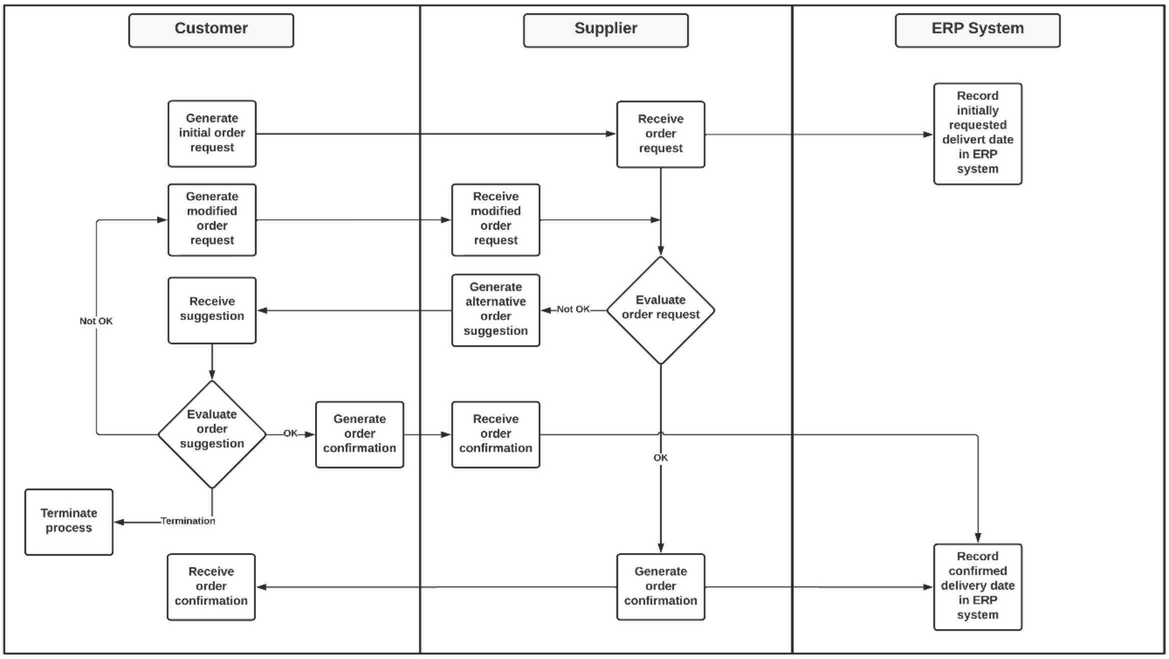


Figure 2 - Ordering process of the case company

The current case study focused on customer delivery orders shipped from the main distribution centre in Europe, where 85% of the case company's turnover was generated. Company distribution centres were also located in North America and Asia, but the sales orders from those locations were not included in the scope of the present study. The data examined in this study comprised a set of 47,323 sales order lines extracted over a 12-month period from June 2020 to May 2021.

4.3. Definition of the metrics used to quantify OTD

As explained by Forslund and Jonsson (2007), four metrics must be specified when quantifying the OTD rate: measurement object, delivery time window, measurement point and comparison date. In this section, the metrics used in the case study are discussed, and ways to handle partial deliveries are addressed. The goal for these considerations was to quantify the OTD rate using both the supplier's confirmed delivery date and the customer's requested delivery date as comparison dates and by considering the data across various delivery time windows. At the same time, all other metrics must be well defined and kept constant.

4.3.1. Measurement object

A common measurement object is the order line, which is traditionally defined as a unique product variant in a unique order. However, in this dataset, some orders consisted of several order lines of the same product variant that were requested for shipment on different dates. Therefore, we defined an order line as a unique product variant in a unique order requested to be delivered on a unique date. Table 8 provides examples that illustrate this definition.

Table 8 – Examples of order line definition

Customer ID	**Product ID**	**Customer-requested delivery date**	**Note**
AB001	XY001	07.01.2020	Unique order lines, as the requested dates differ
AB001	XY001	07.15.2020	
AB001	XY002	07.15.2020	Unique order line, as the product ID differs

4.3.2. Measurement point

Although the agreement made with the customer refers to the date that each order is delivered at the customer site, collecting these data accurately was not plausible because this case study was conducted from the supplier's perspective and was based on data extracted directly from the supplier's ERP system. Therefore, we, instead, used the customer-requested, supplier-confirmed and actual *shipping* dates as the measurement point when quantifying the OTD rate. The shipping date was determined by subtracting the amount of time needed to ship the order from the delivery date

$$shipping\ date = delivery\ date - shipment\ time$$

4.3.3. *Delivery time window*

The delivery time window defines the period during which an order must be delivered to be considered on time. Which time window is most appropriate depends on the requirements and expectations of the customer. For instance, some customers may be willing to accept early deliveries, whereas others will accept deliveries only on the specified date. The expected delivery time windows for individual customers were not transparent in the case company. Therefore, we specified six windows for use in the case study. In this way, we were able to study the variations in the OTD performance that resulted from applying the different delivery time windows. The delivery time windows are shown in Table 9.

Table 9 – The six delivery time windows used in the case study

Delivery time window	**Description**
[0]	Delivery on exact date
[-1;0]	Delivery between 1 day early and the exact date
[-1;1]	Delivery between 1 day early and 1 day late
[-1;2]	Delivery between 1 day early and 2 days late
[-∞;0]	Delivery on exact date or earlier
[-∞;1]	Delivery up to 1 day late or earlier

4.3.4. *Partial deliveries*

When quantifying OTD, a decision must be made on whether to allow partial deliveries. For example, consider an order of 100 units that is split into two shipments – one with 90 units and the other with 10. If only the first shipment is dispatched on time, is the order, then, 90% on time? Or should the entire order be considered not on time? In the current case study, we did not allow for partial deliveries, meaning that if the quantity of products delivered in an order line did not equal the quantity of products ordered, then the whole order line was considered untimely.

4.4. Data cleaning and analysis process

Some of the extracted order lines had a negative or no quantity registered. These orders represent return merchandise authorisations (RMAs), not the physical delivery of a product. Therefore, all these were removed from the dataset. Further, for some order lines, the quantity of products delivered was higher than the quantity ordered. The quantity delivered of these orders were reduced to equal the quantity ordered to avoid the possibility of arriving at an OTD rate of more than 100%.

The result was a dataset containing 47,323 sales order lines. For each order line, the following data were specified: sales order ID, product variant ID, customer ID, quantity ordered, quantity delivered, customer-requested shipping date, supplier-confirmed shipping date and actual shipping date.

5. Results

This section presents the results of quantifying the OTD rate on the extracted set of order data using the OTD metrics specified in the method section (section 4). We present the results going from the most traditional and commonly used analyses of OTD (i.e. those based only on SC-OTD) to more advanced analyses (i.e. those that also consider CP-OTD). Through this approach, we single out and exemplify from a real case a number of improvements from the OTD assessment that companies can identify by embracing Forslund and Jonsson’s (2007) perspective on measuring OTD.

5.1. Supplier-confirmed on-time delivery

As indicated, we started our analysis using the most traditional measure for OTD by quantifying SC-OTD using the case data. Figure 3 shows the distribution of order lines according to the number of days between the confirmed shipping date and actual shipping date. In Figure 3, the dataset is split into several groupings. Between -5 and 5 days, each grouping consists of only a single day. Outside this range, the x-axis changes scale to include several days in each grouping. Note that orders shipped on the exact confirmed shipping date are not shown in this graph because showing them would make the rest of the data unreadable.

Of the 47,323 total order lines, 10,279 (21.7%) were associated with untimely shipping, according to the confirmed shipping date. These order lines were shipped between 213 days early and 91 days late. However, the orders were centred around the middle of that range, meaning that the actual shipping date was close to the confirmed shipping date in most cases. Of the untimely order lines, 79.5% were shipped early, and the remaining 20.5% were shipped late. The results indicate that the case company emphasised that orders were shipped with only a minimal delay, but to a large extent it allowed orders to be shipped prior to the confirmed date. If we could assume that all customers are homogenous in their sensitivity to early deliveries, Figure 3 would provide a good indication of how well the company was able to deliver on what it promised to its customers. However, this case company conducted business with two main groups of customers with different sensitivities to early deliveries. One group followed a just-in-time (JIT) production model and was, therefore, more sensitive to early deliveries, whereas the other group had almost no sensitivity to early deliveries. Therefore, the graph does not provide an appropriate picture of the OTD performance. Cases like this require researchers to dig deeper and use customer groups as contingency factors to achieve a better appreciation of OTD performance and to identify specific improvement possibilities.

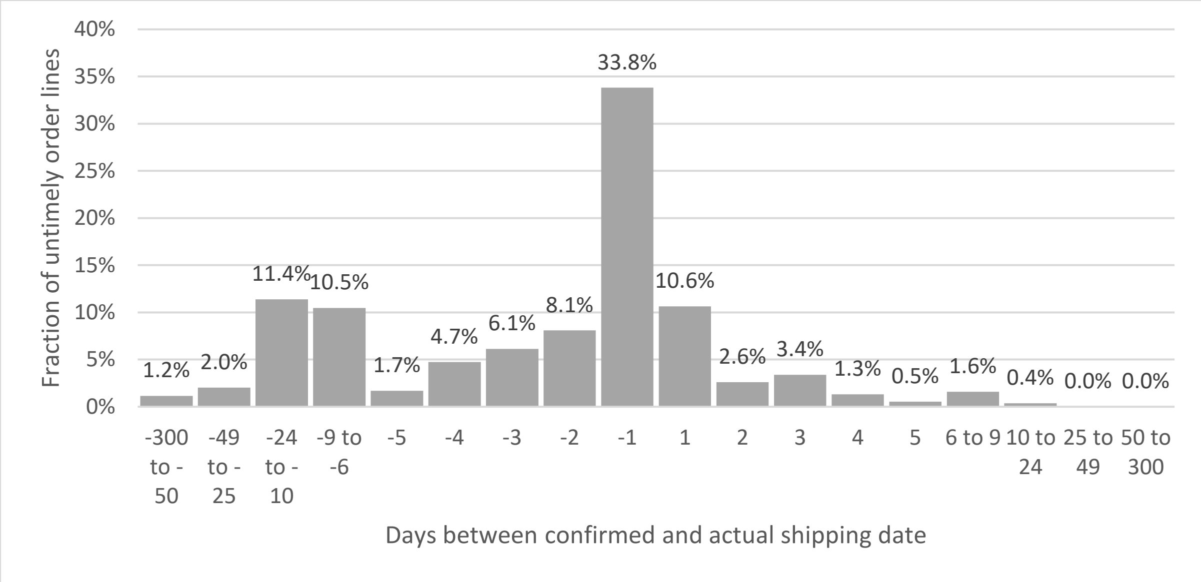


Figure 3 - Distribution of untimely deliveries according to confirmed date

In our case, before delving deeper, we contemplated the degree to which the choice of delivery time window affects the judgement on the OTD performance. We argue that this aspect should receive more consideration both in practice and in research. Figure 4 shows the results of quantifying the SC-OTD based on the case data using six delivery time windows. The results represent delivery time windows that range from those that had to be shipped on the exact confirmed date (77.4%) to those that could be shipped between one day early and two days late (87.6%) through orders that could be early by an unlimited number of days and up to one day late (95.9%). In the company under investigation, the extent to which orders were allowed to be delivered early had a high influence on the performance evaluation. Consequently, the SC-OTD performance was significantly lower according to the delivery time windows that did not allow early deliveries. If all customers had the same delivery sensitivity, meaning that it would be appropriate to evaluate them all according to the same delivery time window, then Figure 4 provides an overview of the company’s SC-OTD capabilities according to different delivery time windows. However, in many cases, such as in the one under investigation, the most appropriate approach is to define different delivery time windows according to the delivery sensitivities of different customers. We, therefore, need to dig even deeper and evaluate customer groups according to their individual appropriate delivery time windows.[1]

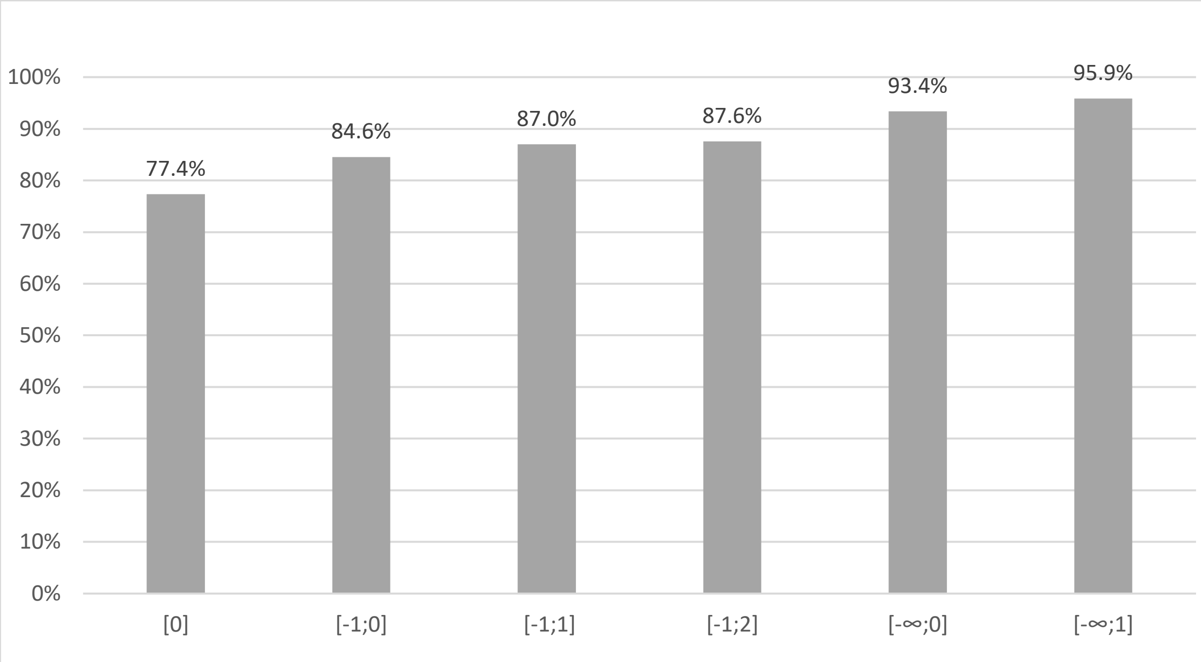


Figure 4 - The SC-OTD using various delivery time windows

5.2. Customer-perceived on-time delivery

In previous sections, we discussed another, less common, approach to measuring OTD – that is, considering CP-OTD. Next, we present the results of quantifying CP-OTD using the case data.

Of the 47,323 order lines, 19,017 (40.2%) were associated with untimely shipping when the customer-requested shipping date was used as the comparison date. This means that almost twice as many order lines were linked to untimely shipping according to the customer-

[1] Figure 4 can also be used to think about the performance implications of moving into market segments that require different delivery time windows.

requested shipping date as were linked according to the supplier-confirmed shipping date. Therefore, the consideration of CP-OTD and of SC-OTD provided two distinctly different overall pictures in the case company. This company was much more capable of respecting the promised delivery date than satisfying the requested delivery date. This insight opens various managerial questions regarding operations capabilities, communication to the market, management of market requests and attention paid to different aspects of the delivery process.

To further analyse the use of CP-OTD, Figure 5 was elaborated to show the distribution of order lines according to the number of days between the requested shipping date and actual shipping date. For details on how to interpret this figure, see the Supplier-confirmed on-time delivery section (section 5.1). The order lines were shipped between 261 days early and 224 days late. Of all the untimely shipped order lines, 42.1% were shipped early and 57.9% were shipped late according to the requested shipping date. The late order lines were more pronounced, with 32.6% being shipped between 6 and 49 days late, while only 14.6% of the order lines were shipped between 6 and 24 days early. This indicates that the case company strived to meet the customer-requested delivery dates and that orders were more likely to be late than early in relation to the requested date.

This consideration of the distribution of the timely and untimely deliveries according to the date requested by the customer provides a good indication of the company’s capability to meet customers’ requests only if all the customers have the same (or very similar) sensitivity to early and late deliveries. However, this was not the situation in the case company. Consequently, a more detailed analysis was needed that considered customers as contingency factors to achieve a more accurate assessment of the performance achieved.

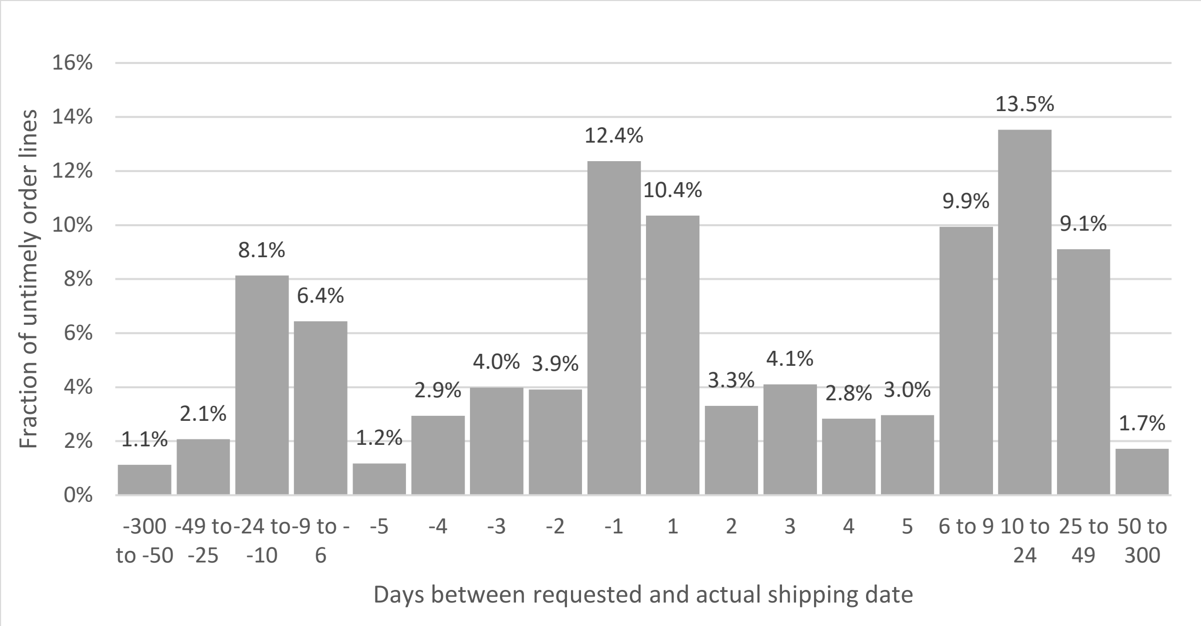


Figure 5 - Distribution of untimely deliveries according to customer-requested date

As in the case of SC-OTD, before going into more detailed analyses, we first considered the effect of the time window definition on the evaluation of the CP-OTD performance. Figure 6 shows the results of quantifying the CP-OTD based on the case data using six delivery time windows. The results reflect a range of orders, from those that were required to be shipped on the exact requested date (58.2%) to those that could be shipped between one day early and two days late (68.6%) through orders that could be early an unlimited number of days and up to one day late (78.6%). This illustrates that the use of different delivery time windows also affected the quantified performance when using the customer-requested delivery date as the comparison date. Again, if all customers were homogenous in their delivery time window, Figure 6 would provide an overview of the company's CP-OTD capabilities according to different delivery time windows. However, in this case study, they were not homogenous. For example, JIT customers had shorter time buckets in their material requirements planning (MRP), as they try to minimise inventory. However, this also means that they have narrower delivery time windows. At the same time, other customer groups used longer time buckets because they prefer to maintain a larger safety stock. These customers are less sensitive to their initial requests not being met on the exact date and are also less worried about early deliveries leading to increased stock.

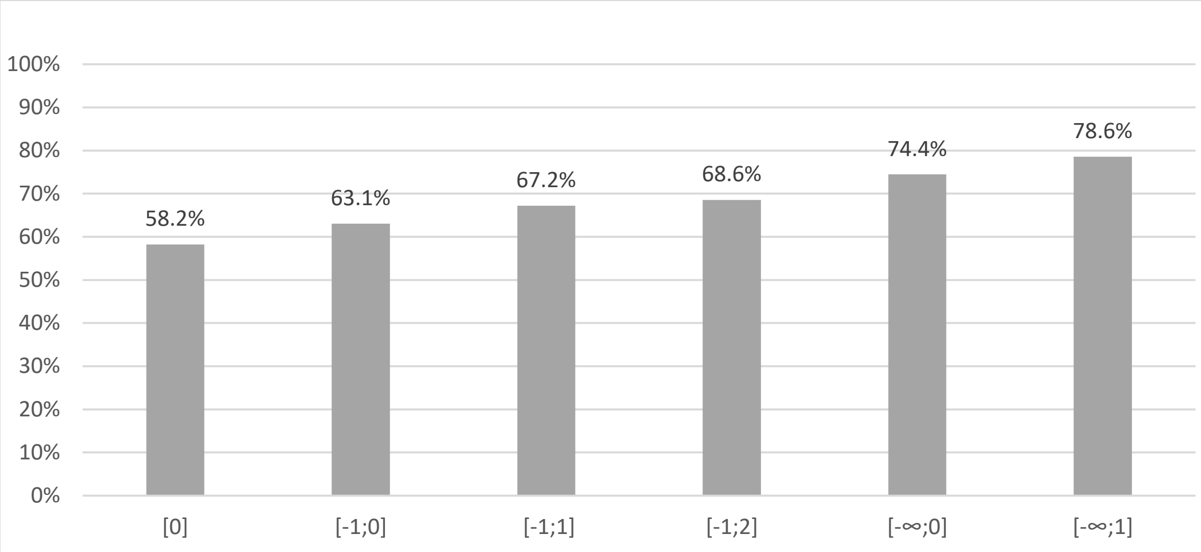


Figure 6 - CP-OTD using various delivery time windows

5.3. SC-OTD vs. CP-OTD

Until this point, we have not considered the possibility of jointly using SC-OTD and CP-OTD. This option is implied by metrics presented by Forslund and Jonsson (2007), but it is not considered in the literature. We started this analysis by displaying the distribution of the order lines according to the number of days between the actual shipping date and both the supplier-confirmed and customer-requested shipping dates (see Figure *7*). The graphical display of these two series of data highlights that in the case company: (a) the actual shipment date tended to be closer to the supplier-confirmed shipping date than to the customer-requested shipping date and (b) the order lines were much more likely to be shipped early when compared with the supplier-confirmed shipping date, whereas order lines were more likely to be shipped late when compared with the customer-requested delivery date.

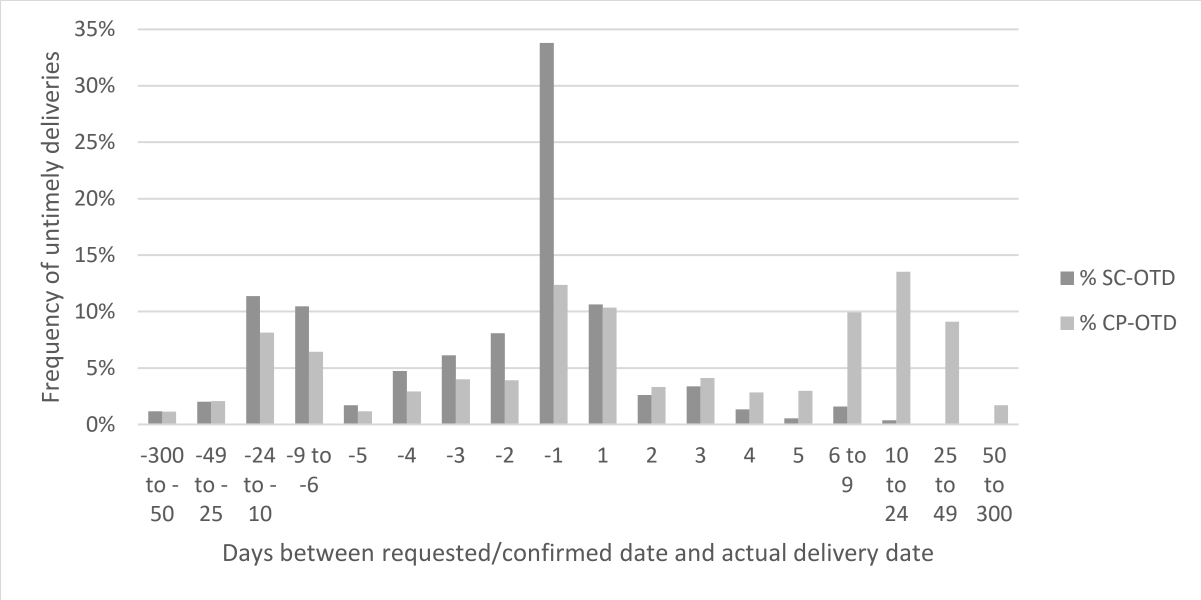


Figure 7 - Distribution of untimely deliveries according to customer-requested and supplier-confirmed dates

A second way to compare CP-OTD and SC-OTD jointly is reflected in Figure 8, which reports the results of a comparison of the two aspects of OTD using six delivery time windows. For example, in the case company, when orders were required to be shipped on the exact date, the SC-OTD was 77.4% and CP-OTD was 58.2%, resulting in a 19.1 percentage point difference in performance rates. When orders could be shipped an unlimited number of days early and up to one day late, the SC-OTD was 95.9% and CP-OTD was 78.6%, equating to a performance difference of 17.3 percentage points. A significant performance difference between 17.3 and 21.5 percentage points existed across all six delivery time windows, with the CP-OTD being the highest across all windows. The graph in Figure 8 shows that the case company's OTD performance was significantly lower with respect to CP-OTD than SC-OTD for all six delivery time windows. This indicates that the case company was, in many instances, not able to meet customer requests but was much better able to meet the delivery date upon which it finally agreed. Previously, this company had only considered SC-OTD. Considering CP-OTD also prompted the company to reflect on the gap between the two performance measures to identify possible areas for improvement. These results have served as a strong stimuli for managers to think about this opportunity to improve the level of services provided.

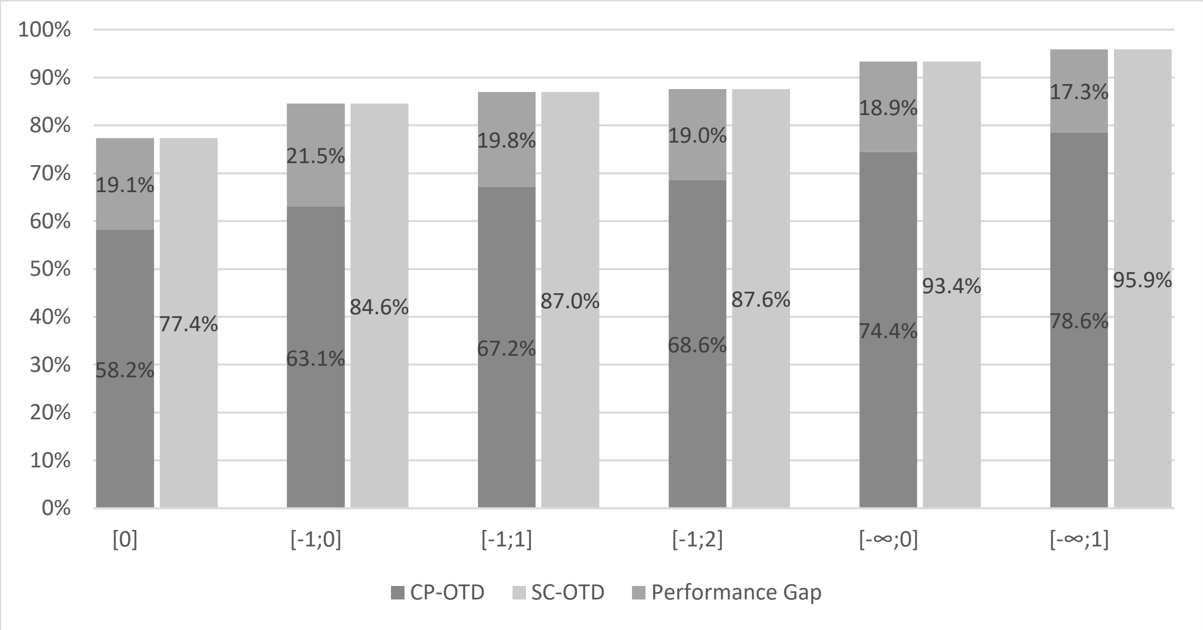


Figure 8 - CP-OTD vs. SC-OTD using various delivery time windows

5.4. Analysis of market contingencies

The joint consideration of SC-OTD and CP-OTD described in the previous subsection captured the interest of managers at the case company. This analysis led them to reflect on whether their efforts along the two OTD dimensions were appropriately distributed. A deeper investigation was required to identify specific improvement opportunities. However, as customers have different delivery time sensitivities, the analyses had to be enriched by considering potentially relevant market contingencies, such as delivery time windows, to identify specific improvement initiatives. The insights that can be obtained by taking this approach can be applied to more accurately assess the OTD of heterogenous customer groups and thereby identify segments, markets or individual customers with improvement potential for the case company.

5.4.1. Customer segments

The case company served two main customer segments. For confidentiality purposes, the nature of the customer segments is not specified. The largest segment contributed to 57% of the order lines, and the second largest segment contributed to 42%. The remaining 1% of the order lines were split across two additional, minor segments.

The two major segments exhibited significant differences with respect to CP-OTD. The fraction of order lines that were not confirmed on the customer's requested date constituted 22.1% for Segment A and 52.6% for Segment B. Thus, the case company was more likely to confirm the delivery requests for customers in Segment A. This may mean either their requests were more reasonable and, therefore, easier to accept, or it may mean that the case company prioritised these orders to give these customers better service. It may also be an indication that the case company's supply chain was better suited for meeting the needs of customers in Segment A, meaning that if the company wished to continue to serve Segment B, then it should adapt its processes accordingly.

When quantifying OTD, a delivery window must be specified. In the case company, as in many other companies, the same delivery time window was used to evaluate delivery timeliness for all customers. The delivery window being used was the most restrictive. In the case company, some customers did not tolerate early deliveries; therefore, the timeliness of shipping orders was evaluated using the delivery time window [0], meaning that only order lines that were shipped on the exact date specified were considered on time. Figure 9 (left side) shows the SC-OTD and CP-OTD of the two main segments when quantified using the same restrictive delivery time window. Here, a significant difference is apparent: Segment A has a higher SC-OTD, and the gap in performance between SC-OTD and CP-OTD is largest for Segment B. These results can be interpreted to mean Segment B contributed to most of the overall difference between SC-OTD and CP-OTD. This performance gap draws the attention of management to the opportunity to increase the satisfaction of customers by increasing CP-OTD rates. Efforts to increase CP-OTD rates may require intensive resource investments, which means that the resulting increase in customer satisfaction may not be worth the additional cost. Nevertheless, the gap still represents a possibility for increasing customer satisfaction regarding OTD; hence, it deserves further consideration by managers to evaluate whether the potential benefits merit the resource investment required.

However, the results of the last two analyses are questionable, as the two segments define being on time differently. Customers in Segment A followed a JIT production model, meaning that they wished to avoid early deliveries, while customers in Segment B were much less sensitive to early deliveries. Therefore, different delivery time windows were needed to accurately evaluate and compare the OTD rates of these two customer segments. The appropriate delivery time window for Segment A was determined to be [0], while [-∞,0] was deemed more appropriate for Segment B. In Figure 9 (graph on right), the two customer segments are evaluated according to more appropriate delivery time windows. In this context, Segment B had a higher SC-OTD than Segment A. This illustrates the importance of using appropriate delivery time windows to evaluate the OTD of customers with heterogenous delivery requirements.

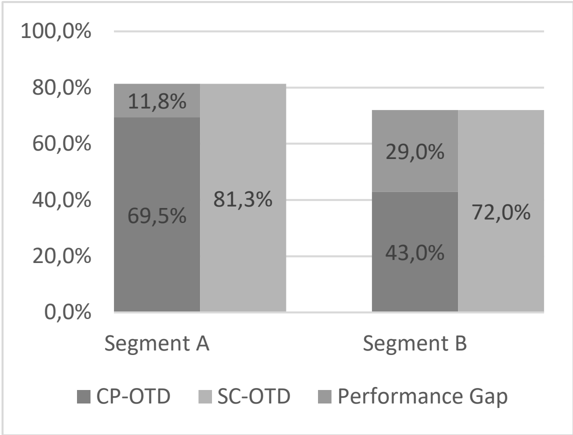
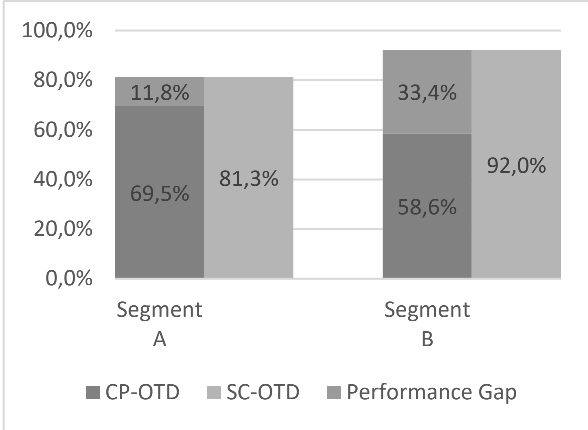
	
OTD using the most restrictive delivery time window	OTD using the appropriate delivery time window

Figure 9 - SC-OTD vs. CP-OTD by customer segment using the most restrictive and most appropriate time windows

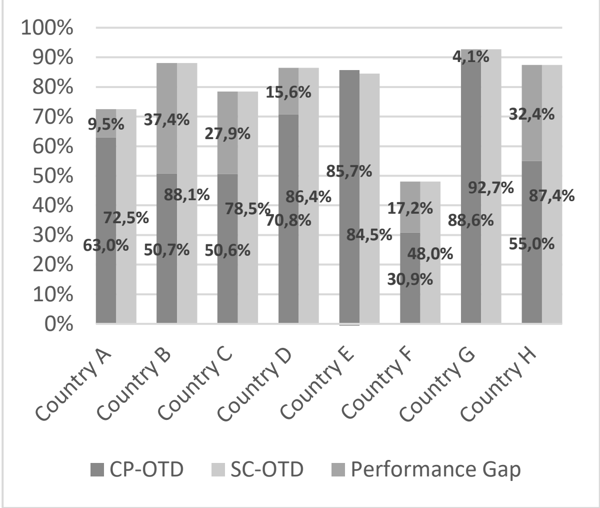
5.4.2. Countries

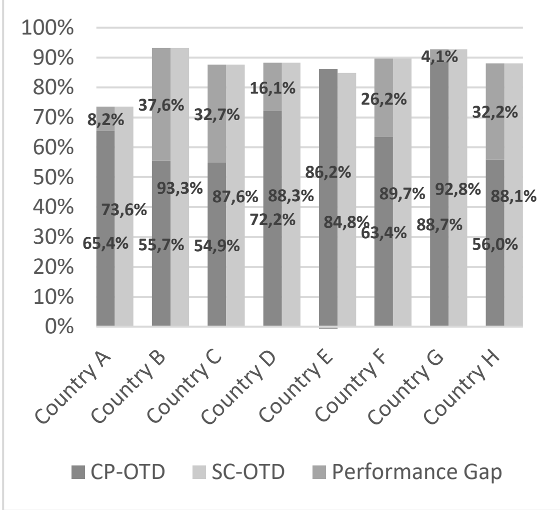
Country may be an important contingency factor for OTD performance. Different cultures, business practices, selling structures and personnel may cause more restrictive or less restrictive customer-requested and/or supplier-confirmed dates. Since the case company operated in more than 40 countries, we analysed OTD considering this contingency factor. Next, we report the results of the analyses of the eight countries where the company sold most order lines.

The initial analysis of CP-OTD revealed a significant difference across countries in the percentage of order lines that were not confirmed for the customer-requested date. For example, the percentages were 15%, 49% and 52% for the first, second and third best-selling countries, respectively. Secondly, a significant difference emerged from the analysis of SC-OTD. For example, considering a time window of [0] produced SC-OTD rates of 72.5%, 88.1% and 78.5% for the first, second and third best-selling country, respectively. These results are illustrated in Figure 10 (left side).

However, we were interested in understanding whether customers were served at different levels of satisfaction across countries. Consequently, the same delivery time window [0] could not be used to evaluate the timeliness of shipping orders to all customers. To avoid this judgement distortion, the timeliness of each order was evaluated according to the delivery time window most appropriate for the customer owning the order (i.e. [0], [-∞, 0], [0] and [0], respectively, for customers belonging to Segments A, B, C and D). The results are reported in Figure 10 (right side). Evaluating order-line shipping timeliness in this way noticeably changed the results. For some countries, like C and F, the change was most significant. This, again, illustrates the importance of evaluating OTD using appropriate delivery time windows when customers have heterogenous delivery requirements.

Using this more accurate measure of OTD, the improvement potential of each country can be identified. Country A had the lowest SC-OTD; however, the reasons behind this result are still under investigation. Countries B, F and H each seemed to be serviced at a satisfactory level when evaluated based on their SC-OTD. However, they each exhibited a gap of more than 30 percentage points between their SC-OTD and CP-OTD performances. This indicates a significant potential to improve customer satisfaction within these countries by improving CP-OTD rates. This improvement potential would not have been apparent if OTD was only evaluated according to the supplier-confirmed delivery date, as was the case prior to this study. Interestingly, Country E was associated with a CP-OTD greater than its SC-OTD. This resulted from several order lines being confirmed for a date different from what had been requested but then ultimately being shipped on the initially requested date.





OTD using the most restrictive delivery time window	OTD using the appropriate delivery time window

Figure 10 - SC-OTD vs. CP-OTD by country using the most restrictive and the most appropriate delivery time windows

5.4.3. Individual customers

In addition to the customer segment and country, single customer specific contingencies may exist. To investigate this kind of contingency, which may lead to very customer-specific interventions, we considered the distribution of order lines that were and were not confirmed for the requested delivery date. This analysis was conducted for the 20 largest customers, measured in number of order lines; the results are displayed for six of these customers, three from Segment A and three from Segment B. However, as discussed previously, to judge whether this service may satisfy or dissatisfy the individual customer, we had to refine the analysis by considering the appropriate time window.

For the six customers highlighted in Figure 11, we collaborated with relevant sales personnel to identify the most appropriate delivery time window. We underline this aspect because some approximations on the time window are acceptable at the customer segment level but are not acceptable at the single customer level. To perform a more robust and precise analysis, we should have considered whether different order lines were subject to different delivery sensitivities with respect to delivery time windows. However, this information was not collected, and it could not be rebuilt after the fact. Therefore, we performed the present analysis to address the potential usefulness of this line of enquiry. The results are reported in Figure 11, and as we did previously, we contrast the results with and without the adjustment for the different time windows to show, once again, the importance of providing appropriate graphs to managers to guide them towards more accurate analyses and, consequently, better improvement initiatives.

As Figure 11 illustrates, Customers C, D and F represent very different situations. Customer C received the lowest SC-OTD rating but showed almost no performance gap relative to CP-OTD, while Customer D received the highest SC-OTD and had the largest performance gap with respect to CP-OTD. According to the SC-OTD assessment, Customer D received excellent service, but when also evaluating the service provided according to the CP-OTD, this customer clearly ranked as under-serviced. However, this improvement potential only becomes visible by evaluating both SC-OTD and CP-OTD.

An additional analysis performed to determine the reasons for the poor service received by Customer C uncovered that 18.6% of the order lines for Customer C were shipped before the confirmed delivery date, which impacts the related performance rating significantly because this customer was not considered to be tolerant of early deliveries. Based on this finding, this customer should be contacted to confirm the specific delivery time sensitivity. Once confirmed, the case company should modify its processes to avoid shipping order lines early to this customer.

The reasons for the large gap between SC-OTD and CP-OTD for Customer D also were examined in more detail. The first hypothesis was that this customer requested unreasonably short delivery lead times. However, further analysis showed that this customer did not request shorter delivery lead times than other customers. Instead, the explanation centred on the type of products purchased by the customer, as these were products that the case company historically had a difficult time offering at short lead times. The case company had been aware of this challenge when evaluating order requests, as 41.5% of order lines for Customer D were confirmed to a shipping date later than what was requested. In most cases, the case company was able to deliver on this confirmed delivery date, causing the SC-OTD of the customer by the customer to be high. However, these insights indicate the potential to significantly increase this customer's level of satisfaction. Implementing initiatives to enable the case company to deliver these products at a short delivery time (e.g. increasing safety stock levels) may increase the CP-OTD of Customer D significantly, potentially leading to increased business or the ability to charge premium prices.

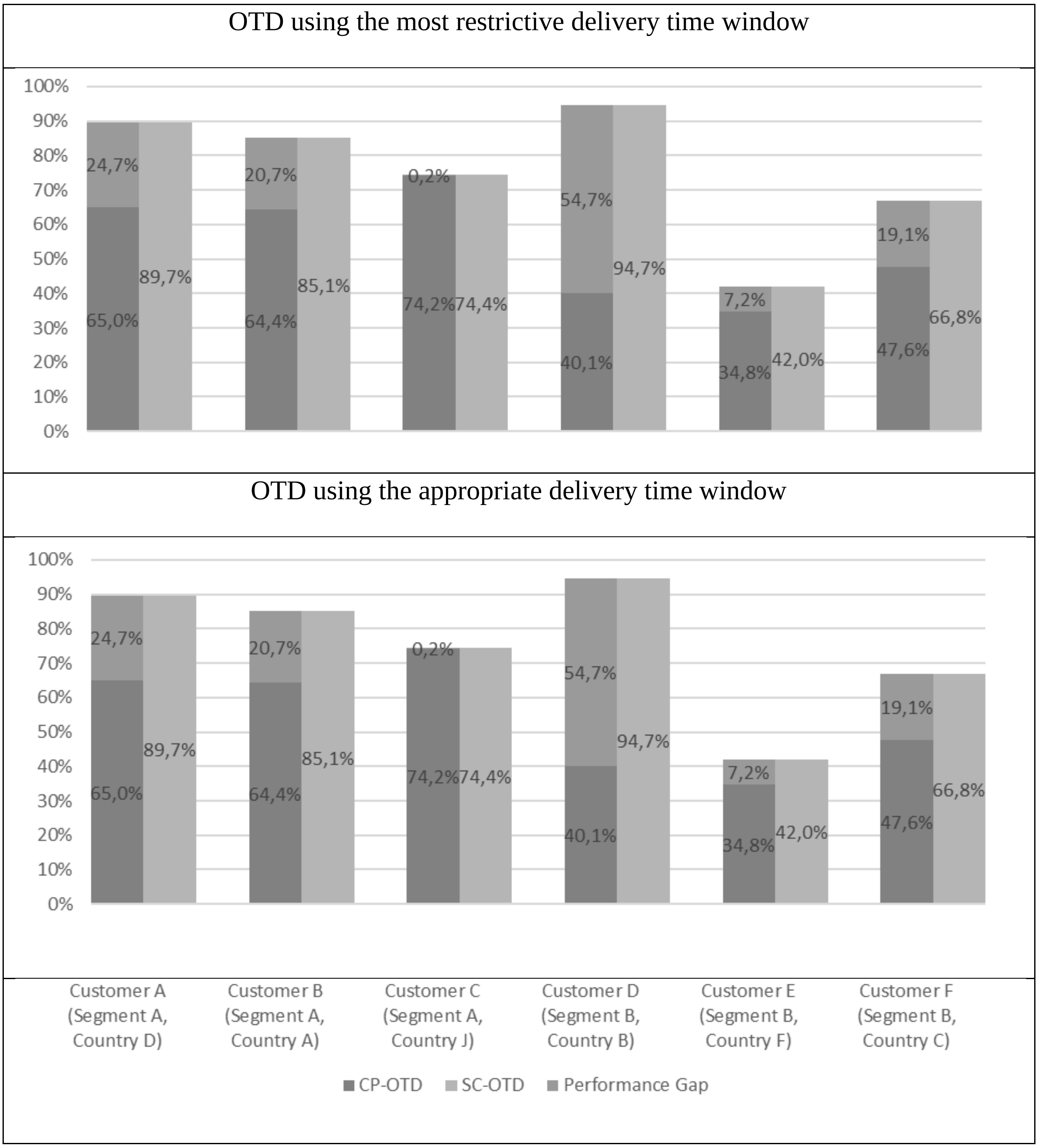


Figure 11 - SC-OTD vs. CP-OTD by customers using the most restrictive and the most appropriate delivery time windows

5.5. Jointly considering customer-requested, supplier-confirmed and shipped dates

The joint analysis of SC-OTD and CP-OTD allows for consideration of the shipped date with respect to both the supplier-confirmed and customer-requested dates; however, it does not consider the relation between the two dates, which may be important in evaluating SC-OTD and CP-OTD and, consequently, in identifying possible improvements. This concept extends

Forslund and Jonsson’s (2007) approach of using different comparison dates to measure OTD. Our concept represents an extension of Forslund and Jonsson’s (2007) approach because they measured OTD by comparing two dates, while we argue that simultaneously comparing all three dates involved may provide additional insights. To explore the potential benefits of this technique for analysing OTD, we developed

Table 10, which classifies order lines according to the joint comparison of the shipping, customer-requested and supplier-confirmed dates. Each comparison is categorised as either earlier, exactly on or after. Additionally, the order lines are divided into Customer Segments A and B (with the two smaller segments omitted from analysis). Impossible combinations are indicated with the “-” character. This table allowed us to compare the OTD evaluations of the two customer segments, which differed in what they considered satisfactory in terms of the combined analysis of the customer-requested, supplier-confirmed and shipped dates. This ‘satisfaction’ is indicated in

Table 10 by the symbols under the number in each cell. This leads to three important considerations.

Firstly, the fraction of order lines that were confirmed on the exact requested date and then shipped on the exact confirmed date was larger for Segment A than for Segment B (67.8% and 41.0%, respectively). Furthermore, the fraction of order lines that were confirmed for a date after the requested date and then shipped on the exact confirmed date was larger for Segment B than for Segment A (26.8% and 7.3%, respectively). This indicates that a trade-off exists in the case company between serving the two segments, as there was a prioritisation to more often meet the requested shipping dates for Segment A, which was more sensitive to delivery time, resulting in a lower level of service for Segment B.

Secondly, the fraction of order lines that were confirmed to be shipped on the exact requested date but were then shipped earlier was 8.7% and 7.8% for Segments A and B, respectively. Potential reasons for shipping order lines early include optimisation of warehouse operations, grouping of order lines to reduce logistics costs or freeing up inventory space. Handling orders in this way was not problematic for Segment B, as those customers were open to early deliveries. However, for Segment A, handling orders in this way led to dissatisfaction because those customers preferred not to receive early deliveries. Therefore, the potential exists to increase the satisfaction of customers in Segment A by ensuring that orders are not shipped earlier than confirmed. However, this process of shipping order early should be continued for order lines to customers in Segment B. Alternatively, collecting the appropriate delivery time window for individual order lines would enable the identification of order lines for which early delivery would not lead to customer dissatisfaction.

Thirdly, the fraction of order lines that were confirmed for a shipment date after the requested date but then shipped on a date before this confirmed date was 4.8% for Segment A and 11.5% for Segment B. Furthermore, the fraction of order lines that were confirmed for a shipment date earlier than the requested date was 8.5% for both customer segments. However, the fraction of these order lines that were then shipped earlier or exactly on the initially requested date was 7.0% for Segment A and 12.6% for Segment B. This indicates that the requested date was kept in consideration in the operations, as the company still attempted to meet this date, even if it had been confirmed for another date. If this interpretation is correct, then a manual process of prioritising orders must exist outside of the ERP system because a formal process of this type did not exist inside the ERP system. However, here, the difference in delivery time sensitivity between the segments becomes important. Customers in Segment B were open to early deliveries; therefore, any time the case company shipped an order closer to the requested date when it had been confirmed to a later shipment date, the satisfaction of these customers would increase. However, this was not always the case for customers in Segment A. These customers were more sensitive to early deliveries as they produced according to the JIT model. If their requested shipment date was not confirmed, these customers might adjust their production plans to fit with the new confirmed shipment date. As a result, the satisfaction of these customers may be negatively impacted by shipping that order line before the new confirmed date in an attempt the meet the initial requested shipment date.

Nevertheless, the delivery of some order lines may be critical to the extent that adjustments of production plans are not possible. In these cases, the customers prefer that the order be shipped before the confirmed date. Therefore, the case company would benefit by identifying the appropriate delivery time windows for individual orders. For example, most order lines for customers in Segment A would use the delivery time window [0], indicating that those customers preferred that the order not be shipped early. However, some orders from the same customers may use the delivery time window [-∞,0], indicating that this order is critical, so it should be shipped as early as possible. Therefore, the potential exists to use the now recorded and stored requested delivery date in the ERP system to develop an automated process to identify order lines with a confirmed date different from the requested date and to then, if possible, prioritise deliveries of these order lines to more closely match the requested date. Moreover, collecting the appropriate delivery time window for individual order lines would further enhance the usefulness of such a process.

Table 10 - Distribution of order lines based on customer-requested, supplier-confirmed and shipping dates

Percentages of total order lines of each customer segment		CONFIRMED DATE HAS BEEN in relation to the requested date: Earlier		Exact		After		Total	
		Split by Customer Segment							
SHIPPING DATE HAS BEEN in relation to the confirmation date	in relation to the requested date	*A*	*B*	*A*	*B*	*A*	*B*	*A*	*B*
Earlier	Earlier	0.7 - -	2.1 + +	8.7 -	7.8 + +	0.4 -	0.8 +	9.9	10.7
Earlier	Exact	-	-	-	-	3.0 **?**	3.2 +	3.0	3.2
Earlier	After	-	-	-	-	1.5 **?**	7.5 +	1.5	7.5
Earlier	*Total*	*0.7*	*2.1*	*8.7*	*7.8*	*4.8*	*11.5*	*14.3*	*21.4*
Exact	Earlier	7.2 +	5.2 + +	-	-	-	-	7.2	5.2
Exact	Exact	-	-	67.8 + +	41.0 + +	-	-	67.8	41.0
Exact	After	-	-	-	-	7.3 +	26.8 +	7.3	26.8
Exact	*Total*	*7.2*	*5.2*	*67.8*	*41.0*	*7.3*	*26.8*	*82.2*	*73.0*
After	Earlier	0.3 - -	0.6 **?**	-	-	-	-	0.3	0.6
After	Exact	0.3 -	0.5 **?**	-	-	-	-	0.3	0.5
After	After	0.0	0.1 - -	2.5 - -	1.9 - -	0.4 - -	2.5 - -	3.0	4.5
After	*Total*	*0.6*	*1.2*	*2.5*	*1.9*	*0.4*	*2.5*	*3.5*	*5.6*
Total		8.5	8.5	79.0	50.7	12.5	40.8	100.0	100.0

\+ + Completely satisfied   - - Completely dissatisfied   ? Situation-specific satisfaction
\+ Mostly satisfied   - Mostly dissatisfied

5.6. Implications for the case company

After being presented with the results of the analyses described herein in progressive fashion, the company managers described feeling both surprised and intrigued. The managers offered comments such as the following: '*I did not expect such a significant difference between the various delivery time windows*' and '*I'm surprised that, according to CP-OTD, customer X receives such poor service*'. Several opportunities for economic gain were identified and discussed. The main points of discussion were the impact of using appropriate delivery time windows, the impact of delivery sensitivity on customer satisfaction and the identification of key customers with low CP-OTD rates. These discussions are further elaborated in the following subsections.

5.6.1. Impact of using appropriate delivery time windows on OTD rate

The analyses performed highlighted the significant impact that the choice of delivery time windows has on performance values when quantifying OTD rates. This choice is especially impactful when deciding whether early deliveries are acceptable. Therefore, the case company implemented an initiative to collect data on the delivery date sensitivity of individual customers. Matching individual customers with their appropriate delivery time sensitivity will enable the company to more accurately quantify OTD rates and increase the precision with which it can identify customer segments, countries and individual customers with the potential for improvement.

5.6.2. Impact of delivery sensitivity on customer satisfaction

The analyses performed provided evidence that the satisfaction of customers regarding the customer-requested, supplier-confirmed and actual shipping dates of their order lines was largely dependent on their delivery sensitivities. After being presented with these insights, managers launched initiatives to further analyse the specific delivery needs of different customer segments. The goal was to use the results of these analyses to modify and customise the service offerings that the company provided to better satisfy the heterogenous needs of different customer segments.

5.6.3. Individual key customers with low CP-OTD

Prior to the case study, the company only measured SC-OTD. Managers were surprised to learn that several important and profitable customers received an acceptable level of service according to the SC-OTD analysis but received a significantly lower level according to the

CP-OTD assessment. This indicated to the managers that these customers may not be as satisfied as previously assumed. As the company relied heavily on the business of these important customers, initiatives were undertaken to meet the delivery requests of important customers more often by confirming their orders to the requested shipping date and then shipping orders on this date. This means that in situations with limited resources, the shipping requests of the most profitable customers were to be prioritised over the requests of smaller, less profitable customers. The goal was to increase the satisfaction of the most profitable customers, leading to increased business.

6. Discussion

Using a supplier's confirmed delivery date to quantify OTD provides a useful internal operational measure of a company's ability to meet its delivery promises to customers. Using the customer-requested delivery date to quantify OTD provides a more direct measure of a company's ability to satisfy the needs of its customers. Although these are both valuable performance metrics, they each measure different aspects of OTD performance. The present article calls for developing and using appropriate combined analyses of these aspects of OTD performance to help managers identify specific opportunities to improve their company's delivery performance.

6.1. Literature review contribution

The literature review showed that most of the relevant articles do not specifically state which comparison date was used in the research described. The lack of such information creates obstacles to accurately interpreting, comparing and replicating studies. This can be problematic when conducting case studies that quantify OTD rates. When case studies uncover improvements in OTD rates, among the crucial details that should be reported with the results is whether the improvement was achieved using the requested or confirmed delivery date as the comparison date. This is also important when conducting surveys asking respondents to assess OTD performance. If respondents are asked on the survey to rate their OTD performance compared to that of their competitors, the use of CP-OTD or SC-OTD must be specified.

The literature review also revealed that among the articles that did specify which comparison date was used, only a few used the customer’s requested delivery date; even fewer discussed or quantified the OTD rate using both the customer’s requested and supplier’s confirmed delivery dates. Many interesting insights on OTD can be explored by following this line of enquiry. Nevertheless, Knoblich, Heavey and Williams (2015) authored the only article that explains a way to exploit this potential by quantifying OTD using both the customer’s requested and supplier’s confirmed delivery dates on the same set of order data; however, their case study models a supply chain specific to the semiconductor industry, and the behaviour of the supplier was regulated entirely by a pre-agreed contract between the supplier and customers. On one hand, this opens an opportunity to consider different application contexts. In fact, in many cases, supplier behaviour is not based on pre-agreed contracts and is, instead, established order by order. On the other hand, the possibility exists to find other ways to exploit the potential of a joint consideration of SC-OTD and CP-OTD, a consideration that can eventually point to new practices to improve OTD.

Forslund and Jonsson (2007) presented a comprehensive framework for quantifying OTD rates, the accurate achievement of which, according to these authors, relied on the use of four metrics. Among these metrics was the delivery time window. Customers have different delivery time sensitivities, and consequently, different delivery time windows should be used to evaluate the OTD of orders to different customers. However, only a few articles reviewed discussed the potential for using several delivery time windows, but none explored the potential of doing so through the analysis of empirical order-line level data. This indicates great potential for collecting and exploiting delivery time window sensibility at the level of single order lines. This information can lead to new measurements of OTD rates and even to new practices to improve those rates.

The literature also highlighted a limited focus in OTD research on studying important contingency factors, such as market contingencies. Only one article was found that examined customer groups as a contingency factor using empirical order level data (Peng and Lu 2017). This article provided an analysis of the impact of supplier performance on future transactional volume and unit price. Hence, the opportunity exists to explore ways in which market contingencies can be exploited to identify specific opportunities for companies to improve their delivery performance.

Finally, the literature review found that only 2% of the articles selected, all of which described case studies, refer to the use of empirical order or order-line level data. Moreover, most case study articles (85%) do not explain the data collection process or the method used to quantify OTD well. Some articles acknowledge an improvement in OTD performance but do not specify the data or method used for the quantification. The findings of this study show that the way information has been collected and processed may considerably impact the results in terms of OTD. Therefore, we recognise the opportunity for future research related to OTD using empirical order-line level data. Performance measurement systems may greatly benefit from this line of enquiry.

6.2. Case study contribution

The empirical part of our study firstly complements Knoblich, Heavey and Williams (2015) by considering a generic supply chain that is not regulated by pre-agreed contracts. Furthermore, we considered empirical data instead of simulated data from a 12-month period, while also involving managers to determine how they appreciated and applied the insights revealed. In our real-life case study, we were able to study the performance difference related to using various delivery time windows and comparison dates. Notably, our methodological approach contains, to a very small extent, an experimentation characteristic because the case company did not record and store the customers' requested delivery date prior to the case study. Therefore, a process for recording these data in the ERP system was designed and implemented under our control. This allowed us to control the data taken from ERP without influencing them and to directly observe the reactions of managers when they were exposed to information not previously available. Although this approach eliminated possible retrospective bias, it did not eliminate the possible bias of researchers directly observing the managers' reactions. To reduce this bias, we shared our observations with managers for their confirmation.

Jwijati et al. (2022) argued that differences in national culture influence the way performance measures are received in manufacturing companies, while Bititci, Firat and Garengo (2013) opined that comparing the performances of companies that operate in different sectors is difficult. The current case study demonstrated that comparing OTD performances within the same sector and culture is even difficult if the underlying metrics are not clearly defined. The results show that OTD performance varied greatly across different delivery time windows and comparison dates. In other words, with the same data, we can obtain different OTD performance outcomes, depending on the delivery time window and comparison date choices made. Therefore, simply stating that an OTD rate of 75% or 95% was achieved is not meaningful without knowing the metrics used for the quantification. Using a single generic number is too limited a view of OTD performance. An improved view can be achieved by using the appropriate different delivery time windows for different customers and using both the customers' requested delivery date and supplier's confirmed delivery date as the comparison dates. The case study also provided evidence that when managers were presented with these results, they recognised ways to exploit these insights for economic value, and various initiatives were implemented to capitalise on these insights. This opens an interesting new line of enquiry that both the case company managers and we found relevant. We have taken the first steps in this research path; however, more research is needed to fully exploit the potential of these findings and for the development of new functionalities in ERP systems.

The case study also showed that using various delivery time windows significantly impacted managers' judgements regarding OTD performance. The appropriate delivery time window to use varies depending on the customer. Therefore, companies should be aware of the delivery time sensitivity of their customers. If companies have customers with different degrees of delivery time sensitivity, these data should be collected and applied when quantifying OTD. When presented with this information, the managers of the case company implemented an initiative to collect and record data on the appropriate delivery time windows to be used for each individual customer. The measurement, analysis and exploitation of customer delivery time sensitivity is another line of future enquiry related to a more fine-grained measurement of OTD.

Finally, the case study revealed that in the case company, a significant difference existed between the CP-OTD and SC-OTD across all delivery time windows. This points to important insights into quantifying both the CP-OTD and SC-OTD. For example, some customers seem to have high OTD performance based on the SC-OTD comparison, but in reality, they have low OTD performance with respect to the CP-OTD. The satisfaction of these customers can be enhanced by increasing the CP-OTD. When being presented with this information, the managers were especially concerned about some of their large and important customers having a high SC-OTD but poor CP-OTD. This difference in performance was not known prior to the case study. Therefore, initiatives were implemented to prioritise and confirm orders from these customers to the dates that they request. This is expected to improve the CP-OTD and, thus, customer satisfaction. Furthermore, initiatives have been taken to analyse specific customer segments and markets that have large performance differences as a way to better understand the needs of these customers and then adjust how the case company serves them.

The main limitation of the present study is that it is based on a single-case study, which limits the generalisability of the findings. However, the situation that was studied – a manufacturing company serving customers with heterogenous delivery sensitivities – is common, so the findings are expected to be valid in these similar contexts. Another limitation relates to the possibility of the same customer having different delivery time sensitivities for different order lines. Thus, the accuracy of the OTD quantification would have been further increased by collecting the appropriate delivery time window on the level of individual order lines rather than on the level of individual customers. These data could not be collected in the present case study. However, this represents an opportunity for future research.

7. Conclusions

OTD is a crucial operative performance that is currently gaining critical importance. The choices of the comparison date and delivery time window are key issues in measuring and managing OTD. The present article addresses these specific aspects by both reviewing the literature dealing with delivery time and by analysing, through a real case study, the different information that can be gained by using and comparing different comparison dates and delivery time windows.

The present study corroborates the idea from Forslund and Jonsson (2007) that to accurately quantify the OTD rate, a more precisely defined measurement apparatus is required. In that respect, by systematically reviewing the pertinent literature, we observed some limitations regarding the accuracy with which OTD is measured. However, one article (Knoblich, Heavey, and Williams 2015) moved a significant step forward by quantifying OTD using both the customer's requested and supplier's confirmed delivery dates. We furthered this line of enquiry by considering more generic conditions, by operating in a real context with real order data, by considering different time windows and by considering market and customer contingencies. With our different enquiry approach, we obtained results that are both practically and highly significant and that open new and interesting research enquires. In particular, our study highlighted the importance of considering market contingencies and of performing a joint analysis of all three dates involved in OTD: shipped, required and confirmed. It also demonstrated that case studies conducted with control of the single order line data, which, although not easy to collect, offer interesting potential for further OTD research.

8. Disclosure statement

No potential conflict of interest was reported by the author(s).

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