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The Influence of Digital Technologies on Supply Chain Coordination Strategies

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Abstract

Purpose – This paper aims to investigate the impact of the strategic transformation of an engineering to order company (ETO) at the level of the internal value-adding chain of operations on its position as a sub-supplier. The transformation is motivated and enabled by end-to-end business intelligence related to processes revolving around the product's design, configuration, and engineering. The investigation builds on a case-based research following the company's decision of converging its product portfolio to only one family of products, thus increasing process efficiency while at the same time enlarging its market reach by offering individualized and innovative products. By digitally integrating operations related to sales, product development and production preparation, the traditional trade-off between cost-effective solutions with high product variety and low lead-time is significantly reduced.

Design/methodology/approach – A design science research project has been conducted to create knowledge on the effects of integration across the value-adding chain of operations. Several design cycles illustrate how development based on business intelligence and available technological enablers for inter-operation integration influence the traditional approach towards supply chain pipeline selection strategies.

Findings – Relating to digital transformation, the consequences and means of adopting digital business intelligence for integrating several administrative and engineering operations in small-medium enterprises (SME) are studied. The product delivery performance of the SME is improved, thus, having ETO lead-time comparable to a manufacturing to order (MTO) company. The findings show how the adoption of state-of-the-art technological solutions for cross-operation digital integration challenges traditional supply chain coordination models.

Research limitations/implications – The conclusions are drawn based on a single case. The limitations associated with case-based research call for further work to support generalization. Furthermore, the long-term influence of the effects of increased interoperability on supply chain coordination strategies requires further investigation.

Practical implications – As technological solutions evolve, new opportunities for supply chain management arise, which put into question the traditional understanding that complex supply chain pipeline characteristics should be handled by complexity reducing initiatives, which opens up new competitive opportunities for companies in high-cost countries.

Social implications – Enabling the use of human resources towards expanding the business (rather than running it only) are aligned with the current economic and political situation in high-cost countries like Denmark and potentially releases skilled employees from repetitive and low value-adding work and reengages them in business development.

Originality/value – By embracing flexibility and volatility as an opportunity, this publication exemplifies how to move beyond hedging the supply chain volatility, but systematically enable the supply chain to deal with complexity efficiently.

Keywords: Value adding chain, Supply chain, Supply chain coordinated strategy, Supply chain strategy selection, Technology, Transition, Configuration, Product configuration, Manufacturing configuration, Interoperability
Paper type Case study

1 Introduction

A key underlying principle of supply chain management is the ability to oversee end-to-end value chain processes as an interconnected system of operations. In line with this principle, it is important to have a system perspective over the operations chain to avoid failure to observe interconnections within the system or to put too much emphasis on one operation only (Forrester, 1961). Moreover, Forrester underlines in his "Industrial Dynamics" book how industrial activities are closed-loop information systems where decisions at any level affect the circumstances which caused the decision in the first place. These concepts have further been demonstrated effectively in the automotive industry (Ohno, 1988). In an automotive supply chain model, variability is detrimental to performance and should be effectively fought. However, in less stable and more dynamic environments, it is desired to employ methods of managing variation and uncertainty (Stratton, 2018), and there are several examples of its effective demonstration (Asmussen et al., 2018). In response to increased complexity and uncertainty in the supply chain context, Christopher & Holweg have been calling for a renewal regarding supply chain thinking and related methods. These methods should enable variability as a basic operating condition (Christopher et al., 2011). Therefore, recent work has revisited the domain of coordinated strategies and the consequences of contextual, organisational, and technological developments in operations management and supply chain management theory (Stratton, 2018; Asmussen et al., 2018). It can be argued that the emerging theoretical understanding has not yet translated into practice or actionable theory (Storey et al., 2005; Stratton, 2012). This is a problem associated with the company's management's understanding of current strategic transitions (i4.0, industrial sustainability etc.), which implies changes to the supply chain design (Storey et al., 2005) and/or product offerings (Melnyk et al., 2010).

Within the case study presented in the hereby paper, it is identified that by employing state of the art technological solutions for cross-operation integration within an engineering to order (ETO) small-medium enterprise (SME), the traditional trade-off between high responsiveness and high product output can be reduced. This is not immediately in line with the established literature on strategic perspectives, which frames the alignment between the nature of product offerings and the design of the supply chain. It is, however, highly motivated by the current economic and political situation within a high-cost environment contoured by the Nordic countries. The new, digital era of manufacturing enables interoperability of both internal value-adding activities as well as external entities of the downstream supply chain. Digital integration across the whole supply chain can increase responsiveness and deliverability towards customer's demands while ensuring the efficiency of internal operations. This introduces the possibility for a wider set of supply chain configuration options where suppliers play proactive roles in shaping customer possibilities and do so without compromising their cost competitiveness (Andersen et al., 2019).

This paper uses a case company from the metal processing industry, heavily reliant on product innovation, which is subject to a major supply chain transition to reach a larger number of customers. The impact of employing state-of-the-art technologies for digital integration of internal operations on downstream supply chain coordination strategies is investigated. Fisher's seminal work on supply chain alignment strategies (Fisher, 1997) is applied as a frame of reference to elaborate and discuss the trade-offs. The question addressed in this paper is:

- How novel technologies facilitate the revoking of traditional trade-offs between high responsiveness and high efficiency while handling high product variety, and how will this affect downstream supply chain coordination?

This paper is structured as follows. Section 2 provides a review of literature on the trade-off concept and coordination strategies in the supply chain theory. Section 3 describes the research method applied. The strategic transition and its influence on product and downstream supply chain characteristics of the case company are presented in section 4. Section 5 analyses and discusses the case in relation to the trade-off theory. In section 6, findings, limitations and suggestions for further research are presented.

2 Background literature

This section contains a review of strategic supply chain perspectives and models for coordinated strategies and the application of digital technologies for integrating operations in the supply chains.

2.1 Strategic perspectives

Stratton (Stratton 2018) conducted a literature review around three strategic perspectives in production operations and supply chain strategy to justify the construct relationships applied to investigate how theory support the realignment within the supply chain following a strategic transition. The three perspectives presented by Stratton (Stratton 2018) are: the trade-off led strategic perspective (SP), the process management-led SP, and the postponement/separation led SP. The trade-off led SP has emerged since the origin of the manufacturing strategy concept in the 1960s (Skinner, 1969). A relevant trade-off example in the context of the hereby paper is between efficiency and flexibility; as Skinner states: "a production system can be designed to do some things well at the expense of other abilities". From this outset, the trade-off led SP to develop to include market criteria (Hill, 1995) and later to embrace the supply chain (Fisher, 1997). However, with the emergence of the process management-led SP, trade-off thinking was challenged (Stratton, 2018).

The process led SP takes the outset in the early developments of process management by Toyota from the 1950s (Stratton, 2018), focusing on reducing waste and improving flow across the supply chain. Womack et al. (1990) demonstrated that performance could be improved by reducing variation and uncertainty in the product, process, and demand profiles, without trade-off consequences (Stratton, 2018). Since recognising that by reducing waste, the importance of performance trade-offs was subsequently reduced (Stratton, 2018). Though the importance of stable and even demand across the supply chain was recognised (Ohno, 1988), it became evident that stable demand and lean manufacturing does not fit all demand profiles. Hence, the term "agile" arose to embrace volatile demand and short product life cycles in the other end of the spectrum to a lean manufacturing strategy (Stratton, 2018). The Reconfigurable Manufacturing System (RMS) has later been coined as the new manufacturing paradigm as it adapts to different demand profiles without compromising on efficiency (Koren et al. 1999; ElMaraghy, 2005; Andersen et al., 2017), as it meets requirements to both responsiveness utilising convertibility and efficiency through dedicated design.

Through product standardization, it becomes possible to postpone the order penetration point where a product becomes customer-specific. In this way, process variation can be reduced across the supply chain, but it requires alignment between market, product, and processes to manage; the importance of the relationships between market, product and process is illustrated by Hayes and Wheelwright (1979). Thus, the postponement led SP allows for demand aggregation using product standardization leading to upstream process standardization separated from downstream processes by decoupling inventory. Consequently, this limits the impact of demand variation and uncertainty on the supply chain (Stratton, 2018). Postponement of product differentiation is closely associated with mass customization (Pine et al., 1993). The manufacturing philosophy of mass customization emphasizes the trade-off reduction between efficiency and responsiveness. However, the implementation of digital technologies seems to remove this trade-off and allow for both increased responsiveness and efficiency, simultaneously embracing both speed and product variety. Therefore, consequences of product or supply chain based strategic transitions met by such technologies might challenge the established models for strategy coordination, which is widely applied by management today to understand the effect of a strategic transition.

The emergence of digital technologies in industrial operations influence the effectiveness and the efficiency of the supply chain, i.e. by allowing for fast and seamless information sharing (Lee, 2002), facilitated by IT connectivity across partners (Wu et al., 2006). Lu (2017) argues that Industry 4.0 is closely related with the wide-spread adoption of supply chain solutions with an outset in the Internet of Things (IoT), Cyber-Physical Systems, Enterprise Architecture (EA), and Enterprise Integration (EI), and further emphasizes that interoperability is the essence of Industry 4.0. However, Industry 4.0 is often associated with isolated technologies such as collaborative robots, 3D printing, or Blockchain, but these technologies are not the essence of this new era of manufacturing, but rather technologies that support this development. This can be related to Forrester's argument on adequately understanding the interconnection between various elements within a system by having a holistic perspective (Forrester, 1961). In the specific context of digital transformation, this holistic perspective is related to the development of inter-operational and connected infrastructures across supply chain functions (Colli et al., 2019), the development of which serves as the theoretical and empirical foundations of this paper.

2.2 Supply chain strategy selection – models for coordination

Stratton (2018) emphasizes the need to unify the trade-off led and process management-led strategy developments. One notable attempt at this is presented by Clark (1996), moving the trade-off frontier between process variety and cost per unit and improving performance and cost simultaneously. By applying the Advanced Manufacturing System (AMS) thinking principles, it is desired to improve both customer performance and cost. Comparable work was presented by Koren et al. (1999), illustrating a limitation of cost per unit through process adaptability applying the Reconfigurable

Manufacturing System. Together with the supporting theory, these examples (Schmenner et al., 1998) illustrate that operating frontiers can be moved through process management strategies, reducing variability and improving flow. These principles are further strengthened by Hopp and Spearman (2001) through their law of variability, stating: “increasing variability always degrades the performance of a production system”.

On the other hand, Miltenburg and Sinnamon (1995) show that product demand cannot be met by completely disregarding variation. It is further illustrated by Hopp and Spearman (2001) that by employing variation management methods, the performance of the manufacturing system can be radically improved, especially when dealing with controllable variation rather than random variation. On the contrary, it is seen that a significant increase in product variety offerings can go hand in hand with increased performance on responsiveness and efficiency through the implementation of state-of-the-art digital technologies.

Fisher’s matrix model has been widely applied to unify strategic perspectives, and it embraces the three strategic perspectives outlined above, illustrating the need to align demand characteristics and supply chain design. However, it will be argued that the definition of the two axes of the model is challenged by the capabilities of state-of-the-art technology since efficiency and responsiveness are not incompatible with complex, innovative products simultaneously. Fisher’s model associates an efficient supply chain with functional products, low variability, and a responsive supply chain with innovative products and demand uncertainty. The model does not seem to stand to illustrate the strategic change related to adopting digital technologies for cross-operational integration and variation management. This can be motivated by having these technologies developed for global trends (i.e. high variability and fast delivery), which requires both responsiveness and efficiency (Koren et al., 1999).

Several approaches for supply chain strategy selection are presented in the literature (Fisher, 1997; Childerhouse et al., 2006; Lee, 2002; Christopher et al., 2006), and they are further developed based on case studies with outset in Fisher’s seminal model as a seminal development. The original model by Fisher (1997) builds on the trade-off relationship between demand uncertainty and supply chain design but has been subject to further development. Heikkilä (2002) has explored how to combine high supply chain efficiency with reasonable customer satisfaction and uses order winning criteria to differentiate the potential customers and compares them to either high or low efficiency in the studied cases. De Treville et al. (2004) discussed lead time reductions as means of managing demand uncertainty. Lee (2002) has further developed the model with constructs embracing the dynamics of shorter product life cycles and highlights the opportunities for information sharing. Likewise, Christopher et al. (2006) investigate what criteria should be applied in the choice of supply chain strategy and emphasizes the need to recognize that agility and responsiveness are critical to success, which has more recently turned into a discussion of cost estimation for supply chain design in the face of operation complexity (Asmussen et al. 2018). Extant contributions, in other words, investigate the construct of design freedom and its relation to supply chain design but do not address the role of digital integration across the supply chain to support design freedom and efficient supply chain execution.

Considering the demand dimension, it is not enough to include the nature of the product only, but also to include the market criteria and their integration in the supply chain flow. It is recognized that the supply chain design must match the demand dimension. However, there is still limited research into what criteria should be utilized to aid the choice of supply chain strategy. The development of the supply chain design dimension seems to reflect methods of meeting a historically changing marketplace. With new technologies comes new methods to meet the dynamic market requirements, which might change the criteria for selecting a supply chain strategy. This development is further investigated in this paper by understanding the impact of new technologies on supply chain strategy selection.

2.3 Cross-operation integration – in the ETO context

It is recognized in the literature that the survivability of manufacturing companies within high-cost countries (e.g. Denmark, Norway, Sweden) is directly related to the quality of manufactured products, processes and delivery dependability (Sansone et al. (2020), Ketokivi et al. (2017)). The empirical findings presented by Sansone et al. are pointing towards several strategy elements relevant in the context of the ETO SME study case presented. These elements are the prioritization mentioned above of developing quality-related capabilities, the openness to change, knowledge-sharing and creativity. The development of capabilities that better fit the competitive priorities focuses on process efficiency and the development of innovative products focusing on high quality and fast delivery. Process efficiency and fast delivery are critical for ETO companies as the customers are exposed to the whole lead-time length. Therefore, Sansone et al. (2020) draw attention towards the innovation and sustainability dimensions of value-adding operations along the already existing quality, cost, time, and flexibility dimensions.

The company's position within the overall supply chain is also essential to address, especially in an ETO company that fits the "technology-focused supplier" description formulated by Andersen et al. (2019). In line with the findings presented by Sansone et al. (2020), Andersen et al. (2019) also emphasize the ability of companies within high-cost environments of attracting customers through their quality-related abilities and their direct and specialized interaction with the customers: "most if not all suppliers engage in some form of adaptation to their customer as part of their value creation process". This is yet another consideration when employing state of the art technologies for digital integration of operations as it can lead towards a decoupling or an engaging strategy towards customer relationship.

The customer relationship of an ETO company is critical when it comes to engineering change (EC) as customer's demands drive their activity. Mello et al. (2015) discuss the importance of cross-company coordination on an ETO supply chain that leads to EC. Iakymenko et al. (2020) find in their study how Norwegian ETO companies manage EC a lack of state-of-the-art digital technologies that help integrate engineering operations within the company's IT framework. Tsinopoulos et al. (2009) identify barriers in the digital technologies implementation process related to lack of awareness and access to these technologies, high perceived associated risk in terms of cost and skill demands.

Efforts were made towards improving the efficiency of EC operations conducted by ETO SMEs, as identified in the literature. Some of these efforts involve creating methods for handling EC project planning and control (Jünge et al. (2019)). The consequences of employing digital technologies for integrating ETO operations conducted by SMEs are scarcely addressed in the literature or not at all. By taking into consideration the digital maturity study proposed by Colli et al. (2019), which has five analysis dimensions: governance, technology, connectivity, value creation and competencies, most of the efforts made to overcome the common obstacles met in an ETO company are related only to governance, value creation (through use of various planning and management methods, presented above) and competences. Understanding the consequences of implementing digital technologies in an ETO SME to integrate engineering and customer relationship related operations by taking into consideration the technology and connectivity dimensions of the digital maturity model proposed by Colli et al. (2019) can bring light into how the established models for strategy coordination can be challenged.

3 Research design

This paper is an outcome of a research project, which, together with several other research projects, constitute a significant national initiative on digitalisation of the Danish industry, i.e. by applying novel technologies associated with Industry 4.0. These research projects seek to come up with practical and viable artefacts for manufacturing excellence. Hence, these projects are well-suited for a design science approach. Similarly, the concerned artefact (i.e. model for coordinated strategy selection) is produced and evaluated in line with the design science research methodology (Hevner et al., 2008). The explicit intention has been to improve the artefact based on demonstration and observation and build and apply the designed artefact in situ. However, more iterations of proving new technologies impact supply chain strategy selection are needed to support the generalisation of the suggested artefact, which was built in this single case study. The construction of the artefact is based on a thorough literature study from which background literature and similar contributions are derived. These contributions are combined with new knowledge derived from the case study and applied in designing the artefact. The case is based on a longitudinal engagement of the authors starting in 2017 with the scoping and design of the process roadmap, which was supported by a pre-analysis of the supply chain (structure, processes, and organisation), solution identification, solution design, solution development (6 design sprints of 1 month followed by a steering group workshop), solution testing through a demo application and validation. This design process was as specified in design science (Holmström et al., 2009) followed by a theoretical reflection of the refined solution and its engagement with the organisational context against extant literature and against an academic-sounding board established to support the overall project, to mature the theoretical contribution and findings. See table 1 below for further details and reflections on research quality.

Quality of research design	**Selection & Design**	**Data collection**	**Data analysis**
Construct validity	Linked with state-of-the-art conceptual understanding.	Key constructs drawn from extant literature.	Triangulated data collection strategy, interviews, steering group

Internal validity	Products selected for demonstration	Multiple sources and respondents to review demonstrations. Cross-case comparison within products portfolio, which have been strategically assessed through the developed solution proposal by multiple respondents (Ellram, 1996). Developing an artifact that solves a practical problem saturates the data collection (Holmström et al., 2009)	meetings, secondary documentation (Yin, 2014). Data analysis in parallel to action phase to be receptive to new results (Eisenhardt, 1989). Draft results viewed by key informants on an ongoing basis (Ellram, 1996). Design sprints and bi-weekly review meetings. Linking and matching to context variables
External validity	Product selected for demonstration based on extreme case selection criteria		
Reliability	Demonstration protocol		

Table 1 measures to increase validity and reliability in the design science work

The study concerns the strategic transition of the case company’s supply chain from a traditional sub-supplier to an advanced solution provider. The case study concerns the case company’s transition within the overall supply chain from the position of sub-supplier towards a position as a supplier of highly customisable products, which can fit a range of customer specifications parametrically, while at the same time keeping the process quality, the product quality and the delivery dependability. The case study covered two and a half years with several visits each month combined with artefacts designed and pretested in a university laboratory. Within this period, the collaboration between the case company and the university has resulted in the digitalisation of essential supply chain entities and made strategic repositioning possible for the case company. Data has been collected during this transition process, making it possible to compare different development stages of the supply chain and related operational capabilities. This comparison of development stages is applied to illustrate how new technology capabilities impact the choice of supply chain strategy to support the thesis that new technologies in some applications can remove trade-offs (i.e. between variety and efficiency).

The development of the artefact in collaboration with the university took off after the case company had already made significant efforts in becoming a more attractive supplier in their market by restructuring their internal chain of value-adding operations through digitalisation. The development of the artefact was conducted in line with the three dimensions of design science research, as proposed by Hevner (2007): relevance, rigour, and central design cycle. The research process is illustrated below:

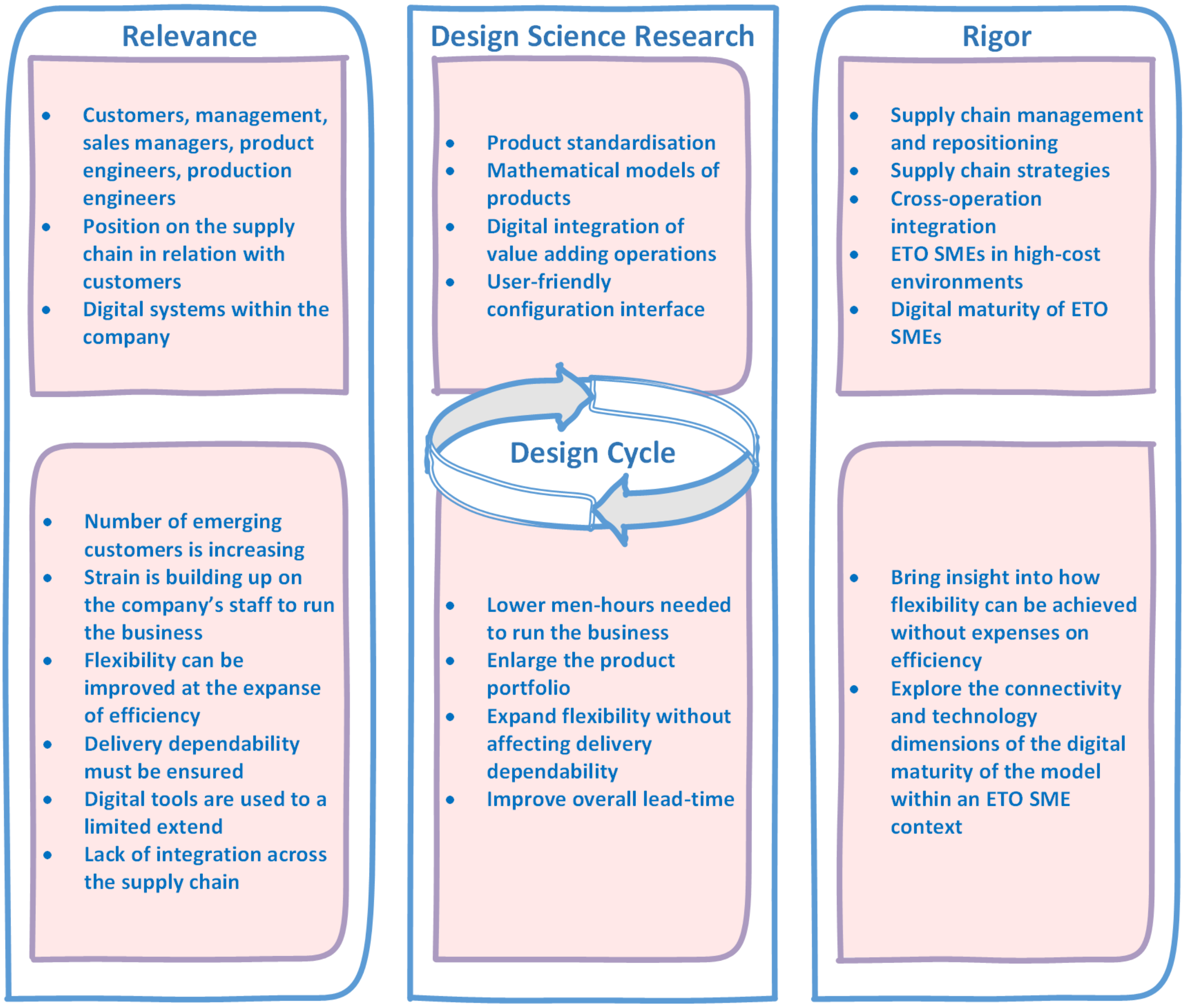

Figure 1: Design Science Research structure adapted within the context of the case ETO company (Hevner, 2007)

4 Becoming an attractive supplier – an industry case

The case company is an ETO SME based in a high-cost country, Denmark. To protect the intellectual property of the company, other product descriptions will be used instead of the real ones, but the key information relevant for the hereby presented research is kept. The main product sold by the company is considered, therefore, to be metal containers specially designed for transportation of various objects or materials, where the main competence of the company is reflected by the engineering operations.

For several decades, the company acted as a high mix/low volume sub-supplier of various heavy fabricated metal structures. A high level of flexibility along the internal value-adding chain is needed to address high product variability and the need for incremental product innovation (OECD, 1992) through engineering changes, as required by customers and by raising competitive standards. To secure the innovative nature of the products, the company relied mainly on manual labour and had to invest in excess capacity to ensure delivery dependability. This high manual labour content in a country with relatively high salaries combined with globalization trends forced the company to redefine itself. Hence, during the last five years, the case company went through several drastic changes in line with the strategy elements associated with a high-cost environment (Sansone et al., 2020). Therefore, to match the product offerings with the available engineering and manufacturing processes, the product palette was reduced to a few products, which reflected the company's competitive priorities and its distinctive competence (Hayes and Wheelwright, 1979). The products left in the portfolio were focused on the large customers and where the customers had direct involvement in the associated design and engineering operations. Typical for an ETO company, the customer is heavily involved in the design, engineering, and incremental product innovation (OECD, 1992) processes of the company, which lead towards the birth of innovative products suitable for highly-specific use-cases. Supply chain restructuring was a natural consequence of these new strategic priorities.

The new, focused product portfolio formed the basis of positive development in turnover. The company had differentiated itself from competitors through openness towards change and by expanding knowledge and experience in what concerns the narrower product portfolio. New customers got attracted by the company's ability to deliver high quality and high customizability on the available products, which increased the number of orders, but also the order complexity.

Being dependent on a few specific customers while having an order number increase from new emerging customers placed the company in a position in which several departments were working under increased strain. As the customers' number increased, so made the demand for more engineering capacity to meet those customer's product requirements. Therefore, the company's resources in terms of sales, engineering and production pre-preparation were poured into running the business, leaving no room for business development efforts such as improving the degree of automation, new product insertion and attracting new customers. Consequently, it was decided to transition towards having dedicated processes and production systems that would ensure high flexibility in terms of product variety depending on the customer's demands. The transition journey of the case company can be explained in three stages presented in Figure 2 and compared with the economic performance in the linked period (Figure 3). The latest transition from the trade-off led strategy towards a postponement led strategy will be further elaborated in the subsections below.

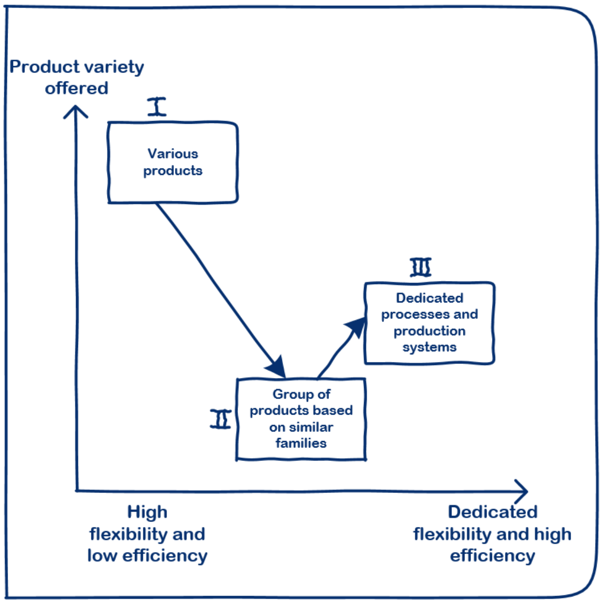

Figure 2 - Adapting processes and production systems to a focused product portfolio and the influence on efficiency

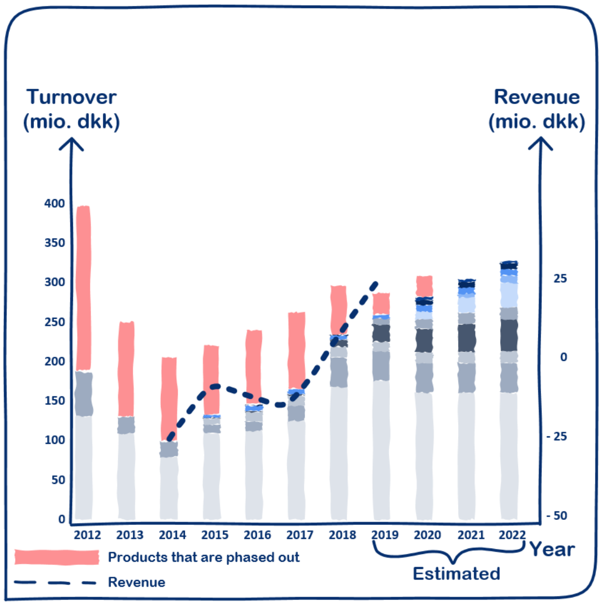

Figure 3 - Turnover and revenue compared to development in product portfolio constituents: pink – phased out products, various shades of blue and grey – innovative product families

4.1 From multiple, various products to families of similar products

As observed in Figure 2, in the initial state (state 1) of the company during the study, the portfolio used to include various products with no immediate connection between them other than the manufacturing processes, which involved metal sheet cutting, forming, and welding. Acting as a do-it-all sub-supplier meant that the R&D department was constantly under heavy load to fulfil the requirements of the customers for a high number of products, basically anything made of metal related to the industry in which the company's main product is used: from structural metal components to casings for moving mechanical components. As the axes in Figure 2 suggest, high flexibility over a high range of products meant a very low efficiency (Hopp, 2001). By removing the products, which were not reflecting the company's competitive priorities and expertise, the company increased efficiency at the expense of cross-product flexibility, thus employing a trade-off led strategy. The efficiency was further increased at the expense of flexibility by engaging digital production hardware like welding robots more than before in the production operations. The impact of the decision can be observed in Figure 3, around the year 2014, where the turnover was mainly composed of products, which were not in the immediate competitive priority of the company (pink). The various shades of grey represent turnover composed of products aligned with the new strategy.

The trade-off led strategy yielded a new market strategy with a complete elimination of products, which did not represent the company priority by the year 2021, thus achieving a consolidated product portfolio. As it can be observed in Figure 3, innovative variations of the remaining products emerged in the company's portfolio, which is aligned with Sansone et al. (2020), who put forward that product innovation is a front-coming dimension of an ETO within a high-cost environment. It is important to mention that these emerging innovative product variations emerged through special performance-enhancing customisations demanded by a specific customer, which later became demanded by other customers too. The innovative nature of the new products is aligned with the incremental product innovation, as defined by OECD (OECD, 1992). The new products are also subject to variations within themselves on customer demand to fit highly-specific use-cases. The high variability of the emerged products also aligns with Fisher's definition of innovative products (Fisher, 1997).

Moreover, as the engineering and production operations became more focused under the ETO paradigm, new customers got attracted by the customised solutions. This is reflected in an increase in turnover represented by a certain family of products in the years 2018-2020. These two factors combined, emerging innovative product variations and emerging customers, results in an increased strain on the company's operations at multiple levels: sales, engineering, production preparation and production. More details about how each of these operations is affected are given in the next subsection. However, from the product's perspective, a commonly applied product strategy would be to modularise and standardise the product and strive to achieve a postponement production strategy. This brings a shift in the company's production paradigm from engineering to order (ETO) to manufacturing to order (MTO).

However, with a traditional Manufacturing-To-Order (MTO) strategy, the company would have to compromise on innovative product variations offerings and hereby compromise their market position as a supplier able to produce optimised designs for the customer. To maintain this market position, a modular product strategy would not be sufficient due to the predefined design space. As a consequence, a hybrid approach was selected in which the opportunities for obtaining two product strategies were investigated. One strategy was to create scalable product models addressed to emerging customers, which could be used to scale the product based on customer requirements in a time-efficient manner and maintained a strategy that kept the ETO paradigm focused on the main customers who demanded heavily customised products.

Through several design cycles in a lab and in situ, it was found possible to construct a mathematical model, which could be driven with a low number of design parameters. E.g., when designing a container, it was enough to specify the desired capacity, and all the other dimensions would be automatically calculated. Having put in place a scalable product model, it was possible to fulfil the emerging customers' need for product diversity. Even though the product model increased the solution space heavily, this will not necessarily impose liability for the company's performance if the variance can be managed (Hopp and Spearman, 2001). How variety is managed is presented in the next section, together with details about how strain generated by increasing orders was reduced by employing state-of-the-art digital technologies. The next section will also shed light on how the final transition of the company is being carried to obtain the desired processes and production systems, as observed in Figure 2.

4.2 Smart SCM through digital inter-operational integration of processes

Part of obtaining the needed efficiency to handle the ever-increasing product variety while maintaining an efficiency level that allows the company to maintain delivery dependability was the conducted analysis of the internal supply chain. Rigid and time-consuming processes were identified. It was revealed that pre-production operations constituted more than 60% of the lead time. These operations are sales, engineering, and production preparation. Common to these processes is their nature of being specification processes, i.e. the employees specify the product or production configurations, also referred to as configuration processes (Hvam et al., 2008). Hence, the process design is directly influenced by the product design. The following steps were being followed along the internal supply chain:

1. Sales employee is contacted by the customer and provided with the desired product specifications.
2. Sales employee contacts the engineering department to consult upon the feasibility of the product design fabrication, and an estimative answer is given to the customer about the fabrication feasibility.
3. The engineering employee receives the product specifications and starts adapting a similar existing product model to fit the customer's requirements. Upon success, documentation of the product is generated and passed to sales.
4. The sales employee contacts the customer and confirms that the product fabrication is feasible. A price is negotiated for the product. The contract between the customer and company becomes binding, and the order cannot be cancelled anymore by the customer.
5. Engineering employee receives fabrication approval from sales and generates the technical documentation of the product (bill of materials, bill of production, technical drawings)
6. Production preparation employee receives the technical documentation of the product. The data is manually inserted into the ERP system, and various tasks are distributed within the department.
7. Different employees start programming the cutting machines, the forming machines, and the welding robots. Depending on how the desired product by the customer varies in comparison with previously manufactured products, it is decided if the fabrication process will be automated, using welding robots or manual, assigned to human welders.
8. Production starts, the product is manufactured and delivered to the customer.

It was determined during the analysis that steps 1 to 7 require more time than the actual production itself to perform, regardless of the complexity of the product configuration desired by the customer. Therefore, it was investigated how these configuration processes could be suitably designed to fit a complex, scalable product design in an Engineer-To-Order (ETO) environment and gain the efficiency level of manufacturing to order (MTO) setup. Novel yet readily available state-of-the-art technologies for the three configuration processes (illustrated in Figure 4) suitable for removing the trade-off between product offerings and performance was chosen to be implemented. Through these solutions, increased efficiency and responsiveness could be accomplished while extending the number of product offerings.

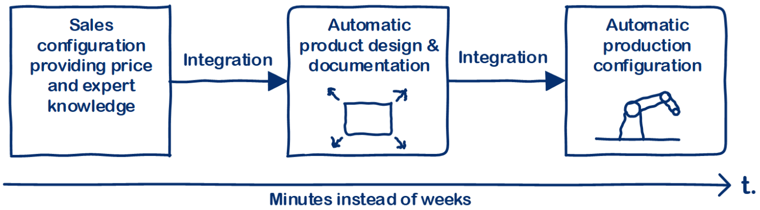

Figure 4 - Integrated configuration processes for a scalable product in an ETO environment and the impact on lead-time

A web-based product configuration system build on rule-based configuration principles was implemented to improve sales-related activities. The product configuration system has an intuitive graphical user interface (GUI) with which the customer can easily configure the product to fit their needs. Within the product configurator, the customer can modify and adjust the parameters, which are normally discussed with the sales employee. The configurator is directly connected with the product model, described in the previous section, through the design parameters specified by the customer. The product model is stored digitally within the configurator. The configurator is built using API (application programming interface) tools available in the CAD software in use by the company. Once the customer inserts the design parameters for the desired product, these parameters drive the overall configuration of the product through the set of rules which are part of the product model. If the product configuration is within the span of the model, the price is computed instantly and displayed for the customer. These steps are performed in real-time by the system while the customer interacts with it. If the customer confirms the order, the technical documentation is generated, the code for the production machines is generated, and the production preparation can begin. By using this configuration system, steps 1-7 listed above are completely automated if the product configuration desired by the customer is within de product model's span. Figure 4 illustrates how sales, engineering and production planning operations are integrated under a single, unified digital system. In Figure 5, it is illustrated how the internal value-adding chain of operations and the downstream supply chain changes in the earlier described three restructuring stages.

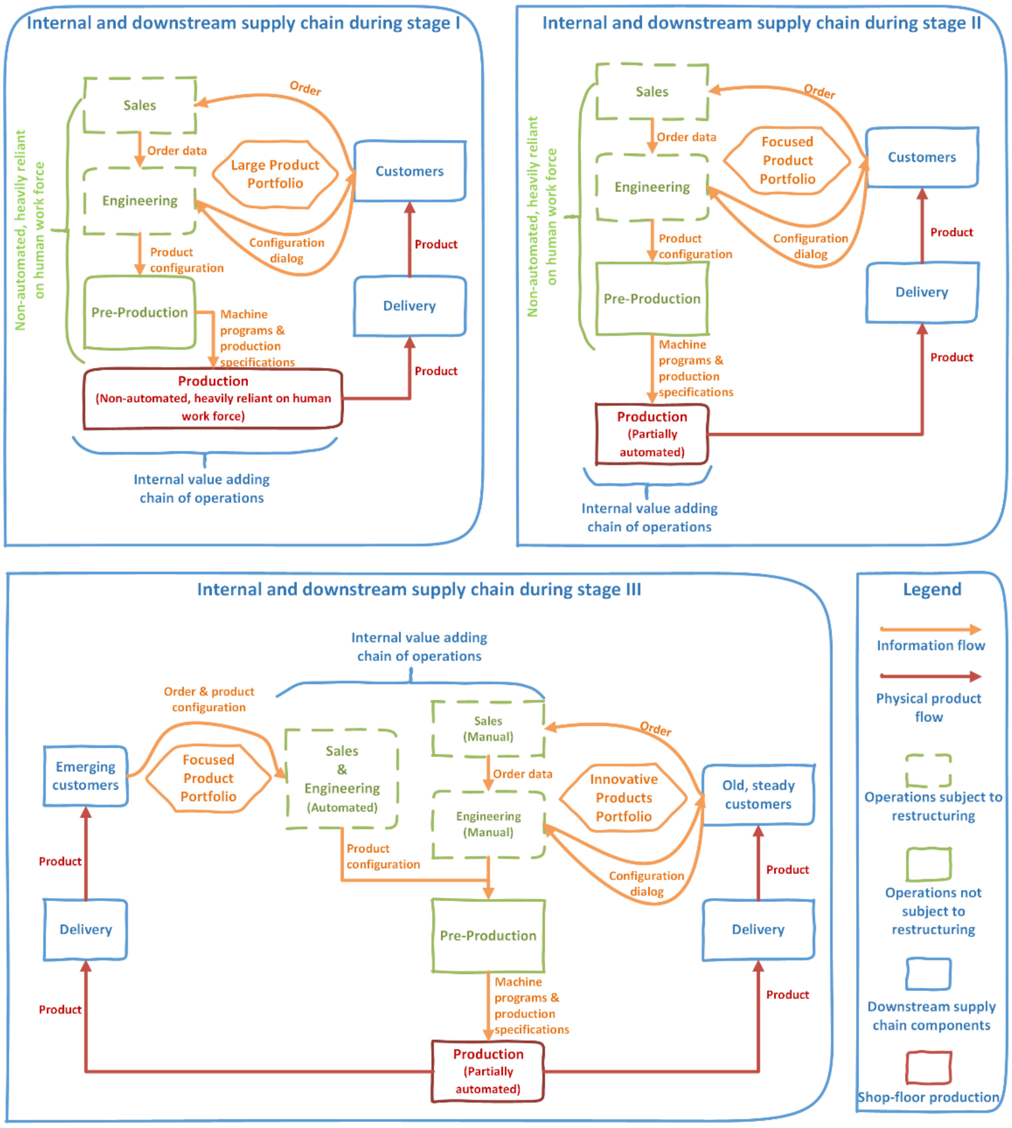

Figure 5 - Diagram abstraction of the supply chain parts being in focus in the three strategic restructuring stages of the company's supply chain pipeline.

In Figure 5, it is showcased how he supply chain pipeline has changed significantly during the third strategic transformation. The immediate consequences of employing this kind of digital system can be felt by both the company and the customer on various levels:

1. The emerging customers receive a clear answer, on spot if their product configuration is feasible or not.
2. The emerging customers are informed about the price of the item on spot, without having to wait until the engineering department is done assessing the order.
3. The design parameters are rigorously represented within the GUI of the configuration system, removing any confusion risk caused by verbal interaction.
4. The engineers are relieved of the burden of configuring products based on specifications from the customers by intervening directly on the CAD model by tweaking and adjusting a high number of parameters defining the product.
5. The contract with the customers becomes binding as soon as the customer agrees with the item's price. The company is not exposed anymore to the risk of the customer rejecting the order after they invested time in determining if the product is fabrication feasible or not.
6. Old and steady customers can still benefit of the dialog between both the sales and engineering departments as more time can be allocated by these departments in creating innovative products together with the customers.

Traditionally, product configuration has not been associated with ETO environments. However, with this kind of product configurators, it is possible to have software that can automatically design the product based on specifications and create the necessary documentation for production automatically. Thus, a product variant, which has never been produced before can be designed, build, and documented in CAD software automatically in just a few seconds. By removing the engineering department's intervention over the product's CAD models, the design and production paradigm is changed from ETO towards MTO. This change is illustrated in Figure 6. However, in case the product configuration desired by the customer cannot be found within the model span, the ETO capabilities of the companies are employed to satisfy the customer.

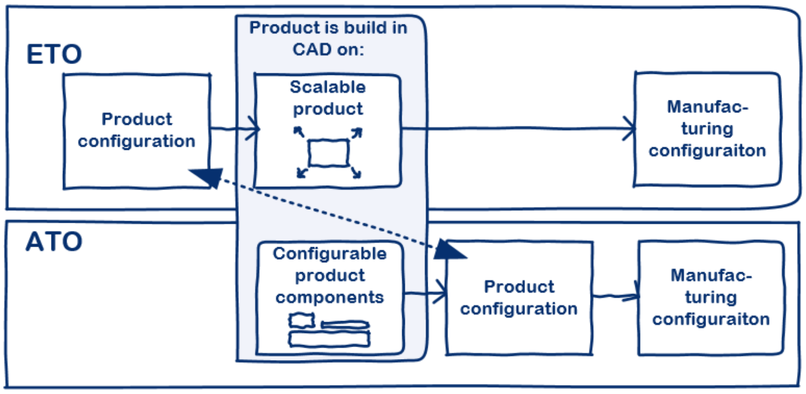

Figure 6 - Illustrating when a product is built in relation to the product configuration process.

With a scalable product and potentially more product variety introduced to the production system, the production technology should also be flexible enough to meet the product design. At the same time, the manufacturing system would have to keep the efficiency and responsiveness from before. Therefore, by implementing a product strategy for a scalable product design, the manufacturing system naturally had to be adapted too.

With the outset in existing machinery, the case company had to identify opportunities to update existing manufacturing technology to cope with more product variety while keeping the manufacturing system's performance. One of the major issues found in introducing the extra product variety followed by the scalable product strategy was the programming of welding robots. The last step in the operations pipeline, presented in Figure 4, is still highly dependent on the degree of complexity of the product variant. The economic production quantity (EPQ) for welding is in many cases higher than the actual order intake of each variant because the manual programming takes a long time, and it can take a year between the same products are sold, sometimes a product variant is sold only once. Therefore, the company find itself in the position of choosing manual welding instead of automated welding to save up on time costs and meet the delivery dependability. Currently, only 40% of the orders are executed using welding robots.

The transition of the case company towards having dedicated processes and production systems has removed or automatised operational tasks and left room for tactical activities. Various tasks along the internal supply chains got integrated under a unified digital system, cutting on the lead time, configuration specification processes and decision-making processes. As the number of customers interested in the company's products increases, these customers are directed towards the automated product configurator, thus engaging the MTO pipeline of the company. Customers with a desire for personalised products outside the product model span are kept engaged within the ETO pipeline of the company. Nevertheless, the attention of the employees is shifted from running the business only towards expanding the business, I.e. the sales person can now spend time on seeking new markets instead of supporting customers in the sales process, the product development engineers can now spend time and R&D activities such as inserting new product families in the product configurator instead of designing most orders from scratch, and the production planning department can focus on optimisation activities instead of spending most of their time on production preparation.

4.3 Findings

Through the design science process, it has been demonstrated in collaboration with the case company that sales, product, and production configuration can be carried out in minutes in a hybrid ETO-MTO environment. In contrast, this process was previously stretched over three weeks. The result of this initiative is summarised in Table 1 and compared with the performance before implementing the digital configuration tool. After focusing the product portfolio on a few product categories and improving the internal flow for that particular product category, the lead time was reduced significantly. After introducing the new product strategy based on a scalable, integrated product design with specific design rules embedded in one product platform, it became possible to meet most of the emerging customers' demands, which were stretching the company's resources in terms of available engineering hours. To meet the customers' demand, the case company previously had to design products outside the product catalogue. Though new variants are introduced to the manufacturing on a weekly basis due to broader solution space, it was only after introducing the new product strategy, which could accommodate foreseen and unforeseen customer needs, it became possible to automatically build all products in CAD software, and it even applies to products that have never been ordered before. Knowing the exact solution space tells exactly the variety potentially being introduced to the production system. Thus, soft and hard configurations can be prepared and therefore meet a wide variety with an efficiency similar to that of functional, standard products if the configuration is carried out simultaneously, not interrupting the flow (e.g. by offline robot programming). The creation of well-defined product design rules was the breaking point for interoperability and communication between sales, product, and production configuration processes. Choosing compatible software with respect to already existing software was the next major struggle and highlighted the need to decide on an IT architecture.

Table 2 - Product and supply chain characteristics (referring to phases in figure 1)

	Phase I: Mixed product portfolio	Phase II: Focused portfolio manufactured without new technology	Phase III: Focused portfolio manufactured using novel technology
Lead time	Long *(35 days)*	Long *(25 days)*	Short *(<10 days)*
New product variant introduction time	Long *(5 days)*	Long *(5 days)*	Short *(Minutes)*
Product variety offered	Innovative *(2000 basic models with the addition of optional add-ons)*	Innovative *(2000 basic models with the addition of optional add-ons)*	Innovative *(Unlimited within the boundaries of the solutions space)*
Demand volatility (volume)	Volatile *(25 % fluctuation in monthly demand)*	Volatile *(25 % fluctuation in monthly demand)*	Volatile *(25 % fluctuation in monthly demand)*

5 Discussion of the influence of state-of-the-art technologies on coordinated strategies

It is clear from the literature and the presented case example that modern supply chains are faced by increasing levels of uncertainty and turbulence (Christopher et al., 2011). The stability seeking paradigm of traditional supply chain configurations is therefore challenged. In the presented case, the increased uncertainty is experienced in several ways:

- Increased competitive pressure, coming from companies outside high-cost environments
- Technology advancements; adoption of new technologies can help to improve efficiency without reducing flexibility
- Ever increasing customer demands in terms of quality, delivery time and product variant/customisability
- External volatility in terms of dealing with a complex supply market.

All these factors challenge the existing coordination mechanisms and the configuration of the supply chain. As these factors emerge, they impact the supply chains, and they create a need to initiate a search for robust solutions to mitigate the effects.

The increasing uncertainty and variation point towards a need for building structural flexibility into the supply chain (Christopher et al., 2011). This is achievable by applying different structural means (open space design specifications, open supplier selection etc.) and by building hedges into supply chain decisions (flexibility/postponement related to choice selection). However, embedding structural flexibility into the supply chain is not sufficient, as the cost of structural flexibility will compromise the competitive position. Truly embracing uncertainty and volatility as an opportunity demands that we move beyond hedging the supply chain volatility and systematically enable the supply chain to deal with these factors efficiently (Asmussen et al., 2018b).

As a means to this capability build-up, the case exemplifies how implementing state of the art digital technologies improves performance (i.e. cost, quality, time) while introducing high product variety and customizability within a product category. This is an effort towards eliminating the traditional trade-offs between performance and variety. The effort is enabled by applying and linking the state of the art digital technologies in a systemic and interoperable infrastructure, which enables the digital integration of value-adding operations across the supply chain. Such supply chains are not covered by the traditional supply chain archetypes of supply chain coordination. In Table 2, the characteristics of the case company's supply chain are compared to the characteristics of the two dimensions constituting Fisher's traditional model to illustrate a mismatch between the model and the case company. In Table 2, the column named "changeable, efficient process" is inserted in Fisher's (1997) original table to illustrate this pursued difference between the three supply chains. The changeable, efficient supply chain representing the case company removes trade-offs and embraces product variety with high efficiency and without postponing differentiation.

Table 3 - Comparison of supply chains (Source: Fisher, 1997)

	Physically efficient process	Changeable, efficient process	Market-Responsive process
Primary purpose	Supply predictable demand efficiently at the lowest possible cost	Rapid respond to fluctuating demand without trade-off between variety and performance	Respond quickly to unpredictable demand in order to minimize stockouts, forced markdowns, and obsolete inventory
Manufacturing focus	Maintain high average utilization rate	Embrace product differentiation in all processes with scalable and adaptable yet efficient processes	Deploy excess buffer capacity
Inventory strategy	Generate high turns and minimize inventory throughout the chain	Minimal inventory on incoming material and no stocks of finished goods	Deploy significant buffer stocks of parts or finished goods
Product design strategy	Minimize performance and minimize cost	A platform design that provides maximum variety yet controlling the functional need exposed to processes	Use modular design in order to postpone product differentiation for as long as possible. Product variety is reduced to reduce trade-off to performance.

In Figure 7, it is illustrated how the trade-off dichotomy underlying the traditional supply chain archetypes (i.e. the efficient and the responsive supply chain) can be abrogated to a certain degree. This is facilitated through the implementation of state-of-the-art digital technologies, which allow manufacturers to handle variety within product families and customisability while at the same time ensuring a certain degree of automation to ensure efficiency. As opposed to supply chains based on traditional demand profiles, the trade-off free supply chain can influence how a company positions itself in the market. However, the demand dimension of models for supply chain alignment differentiates between the functional product and the innovative product (as defined by Fisher, 1997) and reflects the traditional understanding of customers' expectations related to performance and variety. By removing the trade-offs between performance and variety, it changes the traditional view of the demand dimension. In Figure 7 is showed by the expanding arrows that by implementing digital technologies, the trade-off between flexibility and efficiency could be challenged in such a way that the position occupied by the company on the product-process matrix is enlarged enough to cover characteristics of both the "agile, responsive supply chain" and "efficient, lean supply chain" strategies. It is thus explicitly suggested that the traditional trade-off between flexibility and efficiency can be revoked through digital integration.

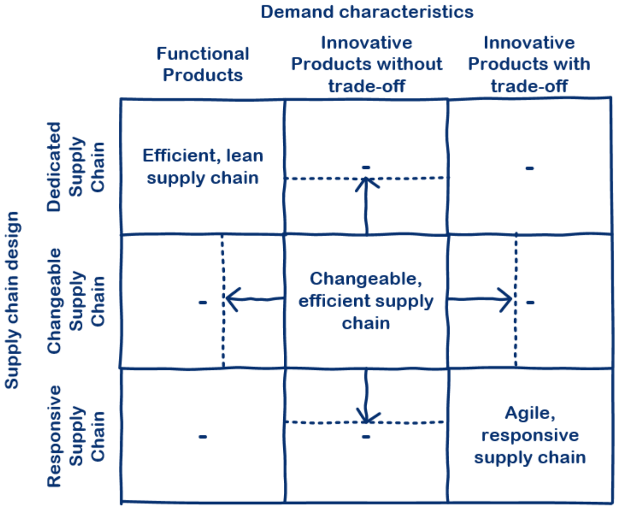

Figure 7 - Matching supply chains with products (inspired by (Fisher 1997); (Christopher, Peck et al. 2006); (Lee 2002))

Over the last decades, a shift in emphasis from process management-led strategies to less awareness of the trade-off implications has been seen. Stratton (2018) argues that the process management view's dominance may help explain why agile and responsive strategies do not actively acknowledge the trade-off implications of dealing with demand uncertainty. However, this development may be ongoing as state-of-the-art technologies lead the manufacturers towards removing trade-off implications.

This study contributes to closing the gap within the literature concerning the nature of product offerings and the design of the supply chain. It is investigated the influence of implementing state of the art technologies on the supply chains in which ETO SMEs are involved. The increasing demand for quality, delivery dependability and flexibility are orienting customers towards manufacturing companies present in high-cost environments. Such are the circumstances that pushed the case company to go through two different transitions. The first transition was marked by the need to reduce the product portfolio, thus embracing a trade-off led strategy. The second transition was marked by the implementation of state-of-the-art technologies and all the underlying perquisites to overcome the trade-off between the need of producing items in an efficient manner and the need of satisfying the needs of the current customers and the needs of the emerging customers at the same time. Taking into consideration the digital maturity model proposed by Colli et al. (2019), it was found that relevant literature on ETO SME management touches only the governance, value creation and competencies dimensions of a company. The hereby study presents a more pragmatic approach focused on the technology and connectivity dimensions of the case ETO SME.

The implementation of state-of-the-art technologies has allowed the ETO SME to restructure their internal value-adding chain of operations in such a way that allows new customers to benefit from highly customised solutions that are typical for an ETO and have delivery dependability typical for an MTO. The said technologies made possible the cross-operational digital integration of sales and engineering otherwise handled manually by sales staff and engineers. This made it possible to have the available human resources invested in the supply relationship with long term customers that have a steady demand for ETO offerings on the company's product. The restructuring of the internal value-adding chain directly influenced the downstream supply chain of the company, allowing it to handle an increased product and information flow.

Further research is needed to complete the hereby study as it is limited to only one ETO SME. Moreover, it is important to mention that the current technological solutions still cannot be applied to the whole breadth of the value-adding supply chain within a company that targets high flexibility without sacrificing efficiency. Within the technological dimension, we found it challenging to include the integration of the welding robot programming since welding is still too complex to fully automate in such a way that a seamless digital chain of operations can be obtained. A tool for off-line programming of welding programs must be developed to automatically generate bits of a program for different welding seams, which can be put together based on a validated library of welding seams. In this way, the new product introduction (NPI) time is going to be considerably reduced, and the number of products automatically welded increased. Fully automatic programming of welding robots is a very difficult discipline and not yet commercially available. However, today both automatic hard and soft production configuration for unknown variety is possible. Hence, by linking automatic product design and automatic product configuration, it becomes possible to respond to a demand for rapidly introducing new products and much more variety while cutting lead time and serving the customers with more efficient supply chains.

6 Conclusion

New digital solutions enable cross-operation integration and rapid response to fluctuating demands of a wide variety and highly customizable products. This claim is supported by the presented case study, which illustrates how connected digital entities of a supply chain can remove traditional trade-offs between variety and performance. Models for strategy coordination do not currently support such a supply chain. Hence, an attempt to further develop Fisher's model on strategy coordination is provided to grasp the trade-off free supply chain. In the last two decades, process management-led strategies have helped companies to reduce trade-offs. Based on the technological development, it is expected that this focus will turn into a pursuance for complete elimination of trade-off, especially between efficiency and flexibility.

The motivation behind investigating the impact of digital solutions on the supply chain pipeline of an ETO company, presented in this paper, takes the outset in previous contributions within the same area of research and further developed based on the case study presented. The intention has been to grasp technological development and include it in a model for strategy coordination. At the same time, showcase the possible practical implications within such a company, presented in detail in Section 4. This model needs further iterations with more company cases demonstrating the impact of technological development on coordinated strategies to be genuinely valid. It is intended so, to validate the theoretical implications illustrated in Figure 7. The global marketplace seems to have created a technological development with digital solutions designed for supply chains to perform better while handling more variety leading to the actual removal of trade-offs. However, more cases supporting this development are needed to obtain a generic model.

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