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Implementing Configurators to enable Mass Customization in the Engineer-to-Order Industry: a Multiple Case Study Research

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Engineer-to-Order (ETO) companies are embracing the mass customization strategy to face the challenges posed by global competition. Product configurators are key enablers of such strategy. Despite the benefits, the actions to perform to manage the challenges of implementing product configurators are still understudied. This paper aims to fill this gap by empirically exploring seven case studies of ETO companies that are embracing a mass customization strategy and have implemented a product configurator. The results provide a classification of the challenges that ETO companies have to manage in each phase of the implementation of product configurators, and a framework that supports managers in defining the actions necessary for the development and implementation of product configurators. This study, thereby, contributes to the debate on how ETO companies can move towards a mass customization paradigm.

Keywords: configurators; mass customization; Engineer-to-Order; case study research

1. Introduction

The Engineer-to-Order (ETO) industry is currently facing pressure due to increased global competition and changing markets, where product life cycles are shortening and there are expectations for time to market to accelerate, product performance to improve, and costs to decrease (Birkie and Trucco 2016; Schoenwitz et al. 2017; Mello et al. 2017; Cannas et al. 2019; Tiedemann, Johansson, and Gosling 2019). Within manufacturing research, a vast array of different strategies has been proposed to address these challenges (ElMaraghy et al. 2013). One strategy which has gained momentum in a high variety of industries is mass customization, which was originally proposed by Davis and popularized by Pine in the early nineties (Davis 1989; Pine 1993). The vision of mass customization is to provide individually customized products at a cost near to that of mass production (Pine 1993).

Initially, mass customization was intended for mass producers, who would be able to gain differentiation and competitiveness by introducing increased product variety at a price near to mass production (Gilmore and Pine 2000). However, as methods and technology evolved, it was discovered that these could also be successfully applied in a context already characterized by high product variety, i.e., ETO industries. ETO products are characterized by an extremely high degree of customization and low volumes compared to mass production (Caron and Fiore 1995). ETO products are typically sold Business-to-Business and, thus, tend also to be highly complex, large, and expensive technical systems (Bertrand and Muntslag 1993; Wortmann 1992). In ETO companies, the customer order decoupling point is located very early in the value chain, which means that engineering is part of the order fulfilment process (Gosling and Naim 2009).

For ETO companies, as suggested by Haug, Ladeby, and Edwards (2009), the incentive to become a mass customizer is reaching the balance between the efficiency of internal processes and the possibility to provide customers with a wide enough choice. To this aim, the literature supports the idea that mass customization in ETO companies consists of the transition from pure custom design and manufacturing to intermediate configurations, i.e., configurations where some parts of both the design and the manufacturing process are performed before the customer order to fulfil different customer needs by reusing existing engineering and production resources (Viana, Tommelein, and Formoso 2017; Grafmüller et al. 2018; Sandrin, Trentin, and Forza 2018; Cannas et al. 2020).

Suzic et al. (2018) identifies eight enablers for mass customization, among which there are IT-based product configurators. In fact, the adoption of a product configurator can support the reuse of engineering and production resources outlined in the previous paragraph (Storbjerg, Brunoe, and Nielsen 2017). Product configurators are the class of software that supports the product configuration process (Forza and Salvador 2002), namely the set of activities aimed at translating customers' needs into product information that supports order acquisition and fulfilment (Trentin, Perin, and Forza 2011). The benefits of applying product configurators in ETO companies are well documented (Haug, Hvam, and Mortensen 2011) and they have proven their value also in those ETO companies that embraced a mass customization strategy (Christensen and Brunoe 2018). In fact, as a result of the increased automatization and standardization that they can bring, product configurators have helped companies by reducing lead times, cutting costs and increasing quality (e.g., Heiskala 2007).

Despite these benefits, implementing product configurators in an ETO company is a difficult task. As any IT system, the product configurator is a complex system to be designed, implemented and maintained over time. Additionally, the characteristics of the ETO context, e.g. the low level of standardization, might amplify these issues, and this still represents a challenge to overcome for practitioners. Indeed, a recent study conducted in the machinery industry by McKinsey (2018) shows that, even if ETO companies are adopting new integrating design and engineering systems (CAx, PLM), the full integration of the product data model with the stages following the product design and engineering (i.e., production and supply chain processes, as well as the rest of the product life cycle) is still missing, and paper-based workflows are still the base, thus not supporting automation and standardization.

This issue, underlined also by the academic literature, has pushed recent studies to understand the challenges that ETO companies need to overcome (e.g., Willner, Gosling, and Schönsleben 2016; Zhang and Helo 2016; Kristjansdottir et al. 2018; Haug, Shafiee, and Hvam 2019a). In particular, the most recent of these studies, conducted by Haug et al. (2019a), focused on a set of case studies that failed in implementing configurators. Building upon the previous literature and the empirical results, they demonstrated that ETO companies must be ready for a profound change of their organization, as well as their processes and products, and introduced a set of guidelines, based on the problems encountered by the cases analysed before, to avoid project failure before, during and after the implementation of the configurator.

The study by Haug et al. (2019a) was a first attempt to overcome a literature gap and provide a general overview to guide ETO companies regarding all the possible actions to take in the different phases of the production configurator implementation. However, the number of cases analysed was limited to eight, the research question was based on the identification of the reasons for project failures (i.e., the challenges) and little details were provided on how to overcome them (i.e., the actions), based on results from failure projects. For this reason, they claim for further in-depth cases on this topic. Therefore, this study aims to empirically validate and further detail the actions identified in the literature, looking at additional cases that successfully overcome the challenges faced before, during, and after a configurator implementation project. This leads to the following research question:

RQ: How do ETO companies overcome the challenges faced before, during, and after product configurator implementation to enable mass customization?

The paper is structured as follows: section 2 presents a review of the literature; section 3 explains the methodology of the study; section 4 presents the case companies analysed, and section 5 shows the main results obtained from the empirical study; section 6 discusses the results and concludes the paper, by outlining the main implications and limitations of the research.

2. Literature background

2.1 Product configurators and implementation projects

A common distinction between different types of configurators is between sales configurators and technical configurators, which depends on whether the configurator is applied during the order acquisition process, or during the order fulfilment process (Forza and Salvador 2006). Forza and Salvador (2006) refer to the process of configuring products during the order acquisition process as the commercial configuration process. This configuration process has the purpose of clarifying customer requirements, in terms of functions and technical characteristics, into an unambiguous representation of the product, that defines a specific product variant. This can then be used for pricing and order fulfilment (Forza and Salvador 2006). Other authors refer to the commercial configuration process using slightly different terms such as sales configuration (Zhang, Vareilles, and Aldanondo 2013; Trentin, Perin, and Forza 2014; Soininen et al. 1998). A product configuration process may also be carried out in the order fulfilment process. Forza and Salvador (2006) refer to this process as the technical configuration process, which they define as “all the activities that generate the documentation of the product variant based on the commercial description of such a variant”. This implies translating the output of the commercial configuration process into a full set of specifications necessary for manufacturing the specific variant. Other authors may refer to the technical configuration process as engineering configuration (Bramham and MacCarthy 2003; Soininen et al. 1998).

Whether the product configurator is a sales configurator or a technical configurator, its implementation project is composed by various steps, like any Information Technology (IT) system. In particular, based on the literature discussing the phases of product configurator implementation projects (Forza and Salvador 2006; Haug, Hvam, and Mortensen 2012; Shafiee et al. 2018; Haug, Shafiee, and Hvam 2019a), three macro-phases can be defined:

- the "pre-implementation phase", i.e., the phase of project scoping, where the companies need to conduct a preliminary analysis to define the customization strategy, goals and priorities, through the review of the products designs, the sales process, the engineering process, the production process, the supplier relationships and the customer ones;
- the "implementation phase", i.e., the phase that encompasses configurator specification, development, and organizational implementation, where the companies acquire the necessary knowledge, evaluate make or buy decisions, define configurator specifications, develop it technically, and integrate it with the organization;
- the "post-implementation phase", i.e., the phase that encompasses operations and maintenance, where companies maintain the configurator and upgrade it, to properly manage new products, new components, new variants, and make sure that the information is always up-to-date.

2.2 Benefits of product configurators in the ETO industry

Introducing a product configurator in ETO industries can have various benefits: (i) reduction of lead time, (ii) reduction of costs, and (iii) improvement of quality. All these benefits are by-products of the high standardization and automation enabled by product configurators.

Indeed, in ETO industries, companies traditionally offer a high degree of customization, and thus the role of the product configurator is to allow customers and salespeople to navigate the variety (Haug, Ladeby, and Edwards 2009). Furthermore, the product configurator can be used for supporting and, to some extent, automating the sales and engineering processes (Kristjansdottir, Shafiee, and Hvam 2017). Also, Hvam et al. (2013) reported as an indirect consequence that implementing a product configurator worked as a catalyst for reducing product portfolio complexity, as unnecessary complexity became more apparent during the modelling process. This is linked to one of the most commonly reported benefits of applying product configurators: the reduction of lead times. When a customer requests a quotation, companies without a product configurator will have to invest engineering hours into designing and calculating cost for a solution, which is time consuming and expensive. Applying a product configurator partly or fully automates this task and, thus, reduces lead times and cost in terms of engineering hours. Haug, Hvam, and Mortensen (2011) analysed 14 cases of product configurators in ETO companies and concluded that lead times were reduced by an average 85.5%, while the engineering hours needed were reduced by 78.8%. They also reported that the time spent on creating specifications for manufacturing was reduced on average by 85.2%.

Another benefit of applying product configuration in ETO companies is increased product quality (Trentin, Perin, and Forza 2012), which may be attributed to the reduction of hoc solutions, configuration errors, and increased focus on improving products incrementally, among others. Hvam et al. (2013) further reported that benefits that could be observed from applying product configurators in ETO companies included that the quality of specifications from the order acquisition phase was increased, and the solutions that were eventually sold and delivered to customers were of a higher quality than prior to implementing the configurator.

2.3 Challenges of product configurators in the ETO industry

When implementing product configurators, ETO companies face different challenges: (i) they need to (re)design the products and the processes for configurability (pre-implementation phase), (ii) they need to manage the product configurator implementation project, and (iii) they need to update the product configurator over time (post-implementation phase). Literature is richer with respect to the challenges related to the implementation project, while the pre- and post-implementation phases are less studied.

(Re)designing the products for configurability may be required in the pre-implementation phase. Indeed, as underlined by Tiihonen et al. (1995), "flexible configuration of products must be considered already while products and components are designed". For example, components and products should have well-defined interfaces and they should not place unnecessary constraints on other parts of the product structure". (Re)designing the product offer is highly complex and expensive in ETO companies. On the one hand, certain companies may have a product range too wide to be fully implemented in a configurator. For example, Forza, Trentin, and Salvador (2006) studied the case of an electric motor manufacturer which adopted a product configurator only for small and medium induction motors, but not for large ones, for economic reasons. On the other hand, other companies may eventually manage to include their entire product range on the configurator, but only after a strong economic and managerial commitment. For instance, the small manufacturing company studied by Forza and Salvador (2002) managed to implement a configurator system without reducing its variety only after fully dedicating one employee to that task.

Product configurator pre-implementation is a challenge also due to the fact that the configurator affects the core processes of ETO companies, i.e., sales, engineering, and manufacturing. These processes might need to be redesigned, such as in the case of FLSmidth (Hvam et al. 2004), and the redesign project might last years (Ariano and Dagnino 1996; Hvam et al. 2004; Barker et al. 1989).

As far as the actual implementation project is concerned, challenges brought by product configurators are the ones typically related to complex IT systems implementation. Firstly, as Haug, Shafiee, and Hvam (2019a) observed, the scope of the configurator implementation project may be too large and/or unclear. In fact, many of the issues found in the eight failed configurator implementation projects studied by these authors were related to the initial scoping phase. Secondly, the costs and benefits of the configurator may be unrealistically estimated, due to their complexity (Haug, Shafiee, and Hvam 2019b). For instance, in the seventh case studied by Haug, Shafiee, and Hvam (2019a), "the expectations for the level of customer use were unrealistic", and in the second one, "the relevance of and motivation for the use of configurators" seemed to be overestimated. This may be an issue because, as Haug, Hvam, and Mortensen (2012) pointed out, it is at risks of being abandoned.

Moreover, the configurator affects not only the IT systems but also the organization, since it changes the roles and tasks of the employees of the company. The survey carried out by Zhang and Helo (2016) showed that 89% of the 64 companies interviewed witnessed some major process changes, while 81% of the respondents had some functional unit changes. More recently, the survey involving 22 manufacturing companies by Kristjansdottir et al. (2018), pointed out that organizational issues were the most frequently encountered challenge, as indicated by 68% of respondents. More precisely, a fist major organizational issue is that employees may be resistant to the introduction of the configurator (Haug, Hvam, and Mortensen 2012). For example, in the case study of a company that produced electric transformers, Cipriano, Forza, and Salvador (2002) found resistance to change from the employees, who perceived the configurator as a threat to their role within the company, since it would automate many activities for both the salesmen and technical personnel. In this context, the configurator implementation project must have proper management commitment (Ariano and Dagnino 1996); in fact, in the absence of a project champion inside the company, the project is at risk of failure. Also, the high technological complexity of configurators may lead to additional organizational problems. In short, the company may lack the technical expertise required to properly develop and manage the configurator (Haug, Shafiee, and Hvam, 2019a; Haug, Shafiee, and Hvam, 2019b; Ariano and Dagnino, 1996).

Finally, as far as the post-implementation stage is concerned, configurators may require high maintenance costs. Heiskala (2007) reviewed several issues related to the long-term management of configurators, including introducing updated configurator models, extending these updates to the entire organization, and checking the correctness of the configurator knowledge after such updates, which may require additional configuration-specific expertise.

2.4 Actions to face the challenges related to product configurators in the ETO industry

Recent studies discuss the best actions deployed to face the challenges related to product configurators. The actions proposed are classified according to the phase of the product configurator implementation project in which they can be used. Hvam, Pape, and Nielsen (2006) outline a six-step framework covering the whole product configurator project. In particular, they stress the importance of analysing the business processes of the company in order to increase standardization, redesign the informative systems in order to feed the configurator with the necessary data, and guarantee its maintenance after the implementation. However, they discuss only one case study (FLSmidth) and do not consider “extended enterprise” issues, i.e., issues related to the relationships between different parts of an enterprise and between the enterprise and the partners in the supply chain. Haug, Hvam, and Mortensen (2012) discuss the different steps that a company should ideally follow in order to implement a product configurator depending on its strategy. However, they do not provide countermeasures to the challenges in which a company – potentially not following one of those specific strategies – may unexpectedly fall. Willner et al. (2016) identify five main maturity stages necessary to achieve a full design automation, which may significantly reduce the costs and lead times of engineering in ETO companies. In this context, they find that adopting sales and engineering configurators is one of the measures employed by the companies willing to automate tendering and order execution. Since their study is related to the broader issue of product configuration for design automation, they do not provide guidelines specific for product configurator systems. However, some of the practices they suggest hold true also for configurators, i.e. the need to increase the standardization of the business processes, the need to redesign the IT systems, and to properly train the employees. Finally, Haug, Shafiee, and Hvam (2019a) study eight cases of failed configurator projects and identify the possible causes of these failures. They then convert these causes into a set of guidelines to prevent future failures in the different stages of configurator projects. This set of guidelines includes the ones mentioned in the previous studies and enriches it; for instance, the importance of properly clarifying the scope of the configurator implementation project is stressed. However, the study presents two main limitations: the fact that these guidelines are based on failed projects, and the fact that the authors do not find empirical evidence to validate the effectiveness of such guidelines by analysing success stories, thus providing few details on the actions. Finally, Zhang et al. (2020) pointed out that few studies dealt with integrated sales, product and production configuration, and while product documentation was considered in some studies, configuration evaluation was often ignored.

2.5 Research gaps

Although some research has indicated various challenges in relation to the development and implementation of product configurators in ETO companies, and some research has prescribed different ways to manage these challenges, little research has analysed the relation between the specific challenges and managing those successfully, with a restricted number of cases and not always specifically related to product configurators.

The study by Haug et al. (2019a) is currently the most recent and comprehensive study that provides an overview of the actions to face the challenges, as it can be seen in table 11, page 129 of Haug et al. (2019a). This table is the starting point of the present work. Despite the relevance of their results, Haug et al. (2019a) suggest future research should be done to engage more in-depth case studies and validate the results. Moreover, it is important to study cases of companies that successfully overcame the challenges of product configurators in one or more than one phase of a configurator implementation project.

This paper aims to fill these research gaps by empirically validating and further detailing the actions identified in the literature, looking at additional cases that successfully overcome the challenges faced before, during, and after a configurator implementation project.

3. Methodology

3.1 Case study design

The aim of the study is to validate and further investigate the actions that ETO companies can take to overcome the challenges faced before, during and after the implementation of configurators to enable mass customization, previously identified in the literature and, in particular, in Haug et al. (2019a). To this aim, the research methodology chosen for this study is retrospective case study research. Case study research follows a qualitative approach, which is considered appropriate and useful to investigate phenomena in their natural setting and generate understanding through the observation of actual practice (Yin 2017). Qualitative studies increase the possibility to understand latent and non-obvious issues and conduct a flexible study, validating and refining the contents analysed, building on models developed in the literature but ensuring that the explanation of the phenomenon remains independent of any previous methodological bias, remaining open to new insights (Mills, Durepos, and Wiebe 2010; Miles, Huberman, and Saldana 2014). Moreover, the retrospective case study is a powerful tool to investigate the timeline of a project and the variables that changed over time along that timeline (Voss, Tsikriktsis, and Frohlich 2002; Street and Ward 2010).

Multiple case studies were performed, since the purpose was to achieve a deep understanding of the challenges and the actions associated with configurator implementation projects. Indeed, our aim is to achieve a broad and general view that can be provided by a variety of cases. Moreover, multiple case study analysis was chosen to have the possibility to compare cases, searching for both similarities and differences between them, and to guarantee external validity (Ketokivi and Choi 2014). The unit of analysis is the project aimed at implementing the product configurator in a company.

A structured approach has been used to collect and analyse the data, with the aim of preventing and/or limiting subjectivity while guaranteeing a consistent interpretation of the results. The application of a structured process is fundamental to assure the internal validity of the results (Seuring and Gold 2012). Moreover, we combined different sources of data, i.e., face-to-face interviews, direct observations (plant visits and/or showing of the configuration in action), and analysis of websites and online resources, to gather information from multiple sources rather than a single origin, thus allowing data triangulation.

3.2 Case selection

According to the research purpose, cases were initially selected according to the following criteria: (i) all cases must be design and manufacturing companies with an engineer-to-order business model; (ii) all cases must be employing mass customization strategies; (iii) all cases must be either initiating or already performing a configurator implementation project, or must have ended one; (iv) cases must differ in terms of size and sector; (v) cases must differ in the implementation stage of the product configurator.

The aim of the first three selection criteria was to ensure literal replication (Miles, Huberman, and Saldana 2014), by making sure that all the companies were homogenous in terms of industry and strategy and, obviously, dealt with a product configurator. The last two criteria, instead, ensured theoretical replication. Criterium (iv) allows for a sample composed of companies of different sizes, different supply chain structures and, consequently, potentially different challenges and managerial practices. Criterium (v) allows for consideration of the implementation, pre-implementation and post-implementation stages, thus giving the opportunity to highlight a possible evolution of challenges and managerial practices over time.

Next, a pool of potentially relevant companies was identified. This was done on the basis of two sources: on the one hand, the authors' previous experience; on the other, a database rich with ETO companies, namely the AIDA database of Italian machinery companies (https://aida.bvdinfo.com/).

The third step was applying the selection criteria to the pool of potentially relevant companies. To check the three criteria, secondary sources were initially used, namely websites and the experience of previous authors. When these were insufficient, emails and direct phone calls were utilized. Finally, through contact with senior managers, companies that showed a willingness for interviewees to participate proactively in the research were chosen. In total, seven case companies were selected, which are presented in Table 1.

------------ *PLEASE INSERT HERE TABLE 1*------------

3.3 Data gathering and analysis

A case study protocol was defined to collect the data. The questions included in the questionnaire were developed to address the main variables and relations present in the research questions, and to cover all the aspects to be investigated to assure completeness to the analysis. The sources of information were face-to-face interviews, company visits, and document analysis. The case study protocol is presented in Table 2.

------------ *PLEASE INSERT HERE TABLE 2*------------

The interview questionnaire was constituted by open-ended questions, which, from a certain standpoint, served to guide the respondents towards the study's research questions (i.e., a functional approach). From another equally important point of view, these questions allowed the informants to talk about other collateral issues. As far as the interviews were concerned, we targeted respondents that had a leading role in the product configurator project and that participated in all phases of the project. Therefore, depending also on the features of the product configurator implemented, the interviewees were Plant Manager, Sales Director, Production Manager, Engineering Manager, Special Projects and Innovation Manager, Chief Product Engineer, and Head of Interior Design. The first interviews lasted at least 3 hours each, plus 1 hour of plant tour. The subsequent interviews lasted approximately 1 hour each. We made audio recordings of all interviews, which were then transcribed. To get confirmation of the data gathered, and – if necessary – gather missing information, we made follow-up telephone calls to the respondents. Data collection also encompassed a company visit and archival data analysis, such as websites, project descriptions, and documentations, to gain a deeper understanding of each project.

The collected data were analysed through a coding process, systematically translating the empirical data into theoretical concepts (Mills, Durepos, and Wiebe 2010). The codes and the categories used for classifying the results were based on the literature (see section 2) and then validated and enriched through the empirical findings. The authors, at first, ran the coding independently and then they compared the results to achieve convergence. Particularly, during the coding process, two kinds of codes were used, namely "in vivo" codes and "constructed" codes. The former were defined by Glaser and Strauss (1967), who termed them as "the very words that participants use in the interview", while the latter are codes built by the analyser. Therefore, constructed codes could be identical to in vivo codes or they could be different and derive from academic theories or from the conceptual thoughts of a researcher. It is important to underline that the approach used during the text analysis process was "deductive" (Ghezzi and Cavallo 2018) because the codes used were based on the theory studied during the literature review. In other words, using the deductive approach, it is possible to ensure that the outcome of the data coding process is well-structured under the theoretical point of view, because everything is constructed in light of the notions already defined by scholars. This allowed the authors to strengthen the reliability of the results. The analytical technique employed was the cross-case synthesis (Miles, Huberman, & Saldana 2014), which allows the researcher in a multiple case study to synthetize the results of each case and compare them across the cases by means of summary tables. This permits us to identify commonalities and differences between the different cases, develop a chain of reasoning and construct interpretations, and draw conclusions.

4. Case studies overview

The purpose of this section is to introduce the reader to the 7 case studies by framing them according to two key aspects of the research questions: mass customization and product configurators. Hence, section 4.1 explains why the 7 case companies can be considered mass customizers, while section 4.2 provides an overview of the configurators discussed in the cases, classifying them according to the type and implementation stage.

4.1 Mass customization strategy

The 7 case companies all feature intermediate positioning between mass production and pure custom design, due to a shift from the latter approach to an intermediate position – namely, mass customization. In fact, these companies managed to anticipate some parts of both the design and the manufacturing process before the customer order, in order to fulfil different customer needs by reusing existing engineering and production resources. Quotes from the case studies support this theory: "…*in the course of past years, we developed a series of possible reusable designs and we defined the components to share between machines of the same family and, also, between different product families*" (company B); "…*over time we chose to shift from pure customization to an offer that provides different predefined solutions for our machines. In this way, we* *can leave customers the idea to freely choose a set of things but, in reality, constraining them to these arrangements*" (company D); "…*we designed, over the years, some standard groups to share between the machines and reuse in different situations, such as the base and pillars of the machines, which can be used for the tightening unit as well as the clamping unit*" (company F).

Due to the higher pressure dictated by the market for shorter delivery time, high quality, and competitive prices, the analysed ETO companies found in the mass customization strategy an effective way of ensuring high product variety together with high efficiency (i.e., time and cost reduction). Some examples from the cases are: "…*we propose a limited number of standard options for the helicopter structures, and some modular kits to add, which share the same interfaces with the helicopter. The modularity between our product families translates into significant advantages in terms of operational efficiency and a reduction in through life costs for the users*" (company A); "…*we share components between our machines because this is a fundamental element to maintain a high-quality level together with cost reduction. Indeed, through the platform-based concept we can reach economy of scale in procurement, increasing the lot size of the orders to our suppliers*" (company E); "…*We don't want to think about different types of machine models anymore, but to conceive our products based on their functionalities and, on this principle, develop the final solution. In this way, we could have more standardized supply chain processes, simplifying suppliers' activities and enhancing the economy of scale*" (Company G).

The transition from pure customization to mass customization has been defined by the companies interviewed as a very complex transition, which requires a reduction in variety and customization without letting the customer perceive this: "…*each customer always asks for different and customized products. Therefore, our sales representatives* *must be able to suggest our modular products, according to the customized application required. […] We recognize that an off-the-shelf product is not always the best solution for our customers' needs and it is very hard for the salespeople to bring them to the standard solutions*” (company C).

As product configurators can help navigate the product variety and automate the sales and engineering process, they can support the transition of a company towards mass customization. All the companies studied were implementing or had already implemented product configurators, as the next sub-section will clarify.

4.2 Product configurator implementation project

As far as product configurators are concerned, this study follows the literature classification between sales and technical product configurators (e.g. Trentin, Perin, and Forza 2011): the former are used in the commercial configuration to define the product characteristics that can satisfy the customers’ needs; the latter are used in the technical configuration to link such product characteristics to the data required to manufacture the product (e.g., the bill of materials).

What emerged from the case studies is that only two companies (company C and company E) have fully developed an integrated configurator, i.e., a configurator that includes both the modules. Instead, the other companies are still stuck at previous stages of the implementation of at least one of the modules. Table 3 contains some key quotations that help understand the present state of the 7 companies.

------------ *PLEASE INSERT HERE TABLE 3* ------------

The firms that have made the least progress towards the completion of an integrated configurator are company A and company G. Although company A has a full technical configurator, it has not started the pre-implementation phase of the sales one, as it still needs to review its products (e.g., by increasing the modularity of designs) and processes (e.g., by automating data exchanges). Company G is in an opposite position, since it has a full sales configurator, but is still in the pre-implementation stage of the technical configurator, since it has not found a way to link the commercial and technical data yet. Company D has completed the pre-implementation phase of its sales configurator, since it has already reviewed its products by increasing their modularity; presently, it is implementing the sales configurator by using a module provided by its ERP system. Similarly, company B has completed its sales configurator, but it still needs to fully implement the technical one. More specifically, the first issue is that the sales configurator can send data to the technical one, but the opposite cannot happen; the second issue is that, for a minority of products, there is still a 1-to-n (instead of a 1-to-1) correspondence between sales and technical codes. Company F completed the pre-implementation phase and is presently undergoing the software implementation of an integrated configurator (conceived, from the beginning, as both a technical and sales system). Finally, company C and company E are the only ones that own an integrated configurator. The two systems are completely different: company C's is web-based and, thus, open to all customers, while company E's software is only for internal use. However, the common trait between these product configurators is that they both now work at full load.

Figure 1 summarizes the different stages of the 7 case companies in their product configurator implementation projects. Looking at Figure 1, it seems that there is no preferential path towards a fully integrated configurator, as companies differ significantly in this sense.

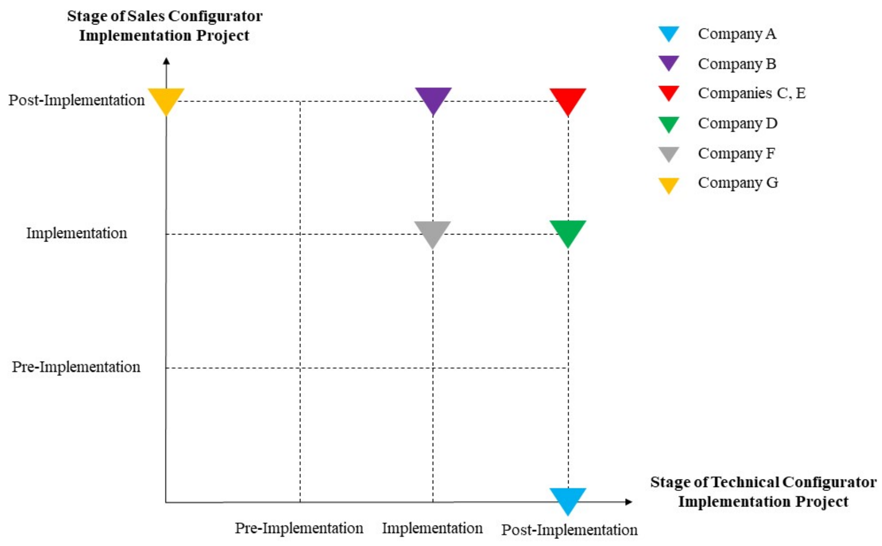

Figure 1. Positioning of the case studies according to the different progress levels in the implementation of sales and technical configurators.

5. Results

In line with the research question of this study, the next sub-sections look at the challenges faced by the case companies during the pre-implementation, the implementation, and the post-implementation of product configurators, and the actions employed to face these challenges.

5.1 Challenges in implementing product configurators: the pre-implementation phase

What emerged from the cases is that it is not possible to start directly with the product configurator implementation because, before reaching this stage, companies need to revise their product design concept, sales, engineering, and production processes, as well as their relationships with suppliers and customers. For this reason, we investigated the challenges related to these four points first. The results are shown in Table 4.

------------ *PLEASE INSERT HERE TABLE 4* ------------

As far as the product design concept is concerned, it is interesting to see that only one company underlined a potential challenge relating to the need to satisfy different customers' requirements, which could be something expected from ETO industries. However, most of the cases analysed agreed that there is a need to reduce useless redesign. This is not easy for ETO companies, which are used to designing everything from scratch, since each customer order is different from the previous ones. On the other hand, it is also true that there are usually some commonalities between customer requests, which ETO companies can exploit by taking full advantage of the product configurator. This challenge is explained, for example, by company E: "…*We used to redesign all the components of the machines for each new order, even if there were some commonalities with past projects. Then, we realized that this approach would have made the configurator implementation useless. Therefore, we face the challenge of rethinking our approach to new orders so that we can exploit past experience through the product configurator and have more time to perform value-added engineering activities, i.e., the ones related to completely new innovative designs*". Also, most of the cases agreed that there is a need to close the knowledge gap that exists between customers and designers, bringing the design process towards an easier *"configuration process"* governed by *"configuration rules"* that can support customers in identifying their solutions, while minimizing complexity and burden of choices. This is not easy for ETO companies, as explained by company D: "…*We usually do not analyse the market trends because of the high customization we offer, but this is important for configurator implementation. We should understand if a request is a spot or a trend. Otherwise, the risk is to implement a product configurator full of useless options and a myriad of choices. This could increase* *the cost of evaluation for the customer, which would outweigh the additional benefit from having a product configurator*".

As far as the (re)design of processes is concerned, the cases underlined this as a need for all of the processes involved in the order acquisition and fulfilment, i.e., the sales, engineering, and production processes. Three companies agreed on the challenge to redesign the sales process, since usually salespeople do not consider engineering constraints when configuring the product with the customers during the offer. Therefore, the need is to exchange information between the two departments so that salespeople have the knowledge to configure the product while also considering the engineering needs. It is also important to work on sales and engineering departments alignment. Indeed, as explained by company F: "*…Before implementing product configurators that support salespeople in configuring autonomously the products with the customers, it is very important to align them with the engineers. In our context, they are usually very misaligned, and the risk is that the salespeople do not estimate the price in the right manner and make wrong choices*".

Six out of seven cases underlined the need to redesign the engineering process to allow the anticipation of some activities before the customer order arrival and reduce engineering costs, as explained by company G: "*…Usually, in our industry, companies start developing products only when there is a customer's order, never in advance, because of the high customization of the products. This makes the engineering and production processes very expensive and does not make it possible to exploit the product configurator. Therefore, we need to move towards design concepts that are different from the past, and which make the engineering and production process less expensive and allow us to acquire benefits from the product configurator*". Additionally, all of the companies highlighted the need for engineering redesign for rapid adaptation of the configurations by automating some engineering activities, as company B explained: "…*In the past, we executed some actions manually and we had no integration between different systems. Then, we realized that, to implement the product configurator, there is a need to facilitate rapid adaptation of the configurations and to automate some activities. Thus, we needed to change our way of working*".

Finally, as far as the production process is concerned, most of the cases underlined two main challenges. First, the need to redesign the production process in order to be prepared for the increased production volumes brought by the increasing level of design standardization and the need to anticipate production activities before the order. Second, the need to redesign the production process to maintain the production flexibility required by the ETO market and assure that the customers do not suffer during the shift to mass customization that the product configurator is supporting.

Additionally, the cases underlined that relationships with suppliers and customers are also affected by the introduction of the configurator and must be managed before the implementation to ensure their support while using the configuration system. In line with the needs presented for the production process, some of the companies interviewed also underlined that the suppliers, in the case of outsourcing, must be able to support the shift through mass customization and the implementation of the product configurator by ensuring the flexibility required by the ETO sector, while positively responding to the need for increasing standardization and production volumes. Also, the engineering activities required support from the suppliers, which should be open to the collaborative redesign of the product to ensure the configurability and automation of sales and engineering activities through the configurator, whenever possible. Also, most of the cases underlined the important challenges with customer relationship management, which are the need to precisely identify customers' requests and the need to create a digital solution space. For example, according to company A: "…*When we decided to start the journey of configurator implementation, we realised that there is a need to anticipate customers' requests. We understood that there are some solutions which are more requested than others. So, we grouped them inside a solution space, i.e., a product catalogue, creating four basic solutions. In doing so, we had the issue of changing our products design and deeply analysing all the components, but it helps in clarifying ideas between what the customer wants and what is feasible […] Once customers' requests are identified and a catalogue defined, the next challenge is to digitalize the solution space and move towards digital instruments, changing the actual way of working*".

5.2 Challenges in implementing product configurators: the implementation phase

During the implementation of the configurator, there are challenges that can be linked to two main aspects: the specification and development of the configurator itself, and the organizational aspects.

In the implementation phase, companies may lack the competences to code a system as complex as a product configurator. As explained by company F "…*Without having a clear knowledge and the right competences related to a product configurators characteristics and purpose, the project could result in failure"* because, as underlined by company A: "…*Product configurator implementation requires high technical knowledge related to competences that are not usually already owned in our context*". Therefore, there is a need for competences upgrading to overcome the lack of knowledge related to the product configurator structure and functionalities. Also, a lack of synergies between departments has been underlined as an important problem to extend the technical knowledge related to product configurators between departments and solve the lack of competences.

Another challenge in this phase is related to software integration with all other IT systems present inside the firm and/or those of the external partners. As company E underlined: "*Our product configurator faced many evolutions because it is a small part of the entire IT structure that manages the company. It is only one element that needs to interact with all the other systems, such as the production one, the accounting one etc. Thus, at the beginning of the project, we had some integration issues*".

In terms of organizational aspects, there is the need to change habits in the implementation phase because the product configurator changes the established work actions, changes personal roles, and requires the process to follow specific rules and pay high attention to the avoidance of errors during the procedure. As company B stated: "*…Our salespeople, in the introduction phase, thought they had less negotiation freedom and less possibility to customize the offerings towards customers, because of less reliance on human relationships. The configurator limits their freedom of action, constraining them inside well-defined rules, which can be a benefit for the company but must be well justified to the salespeople*".

Table 5 summarizes the challenges underlined by the cases for the implementation phase.

------------ *PLEASE INSERT HERE TABLE 5* ------------

5.3 Challenges in implementing product configurators: the post-implementation phase

As far as the post-implementation phase is concerned, companies see challenges in the need for product definition, in terms of knowledge adaptation, product updates, new product launches, customer requirements, and the need to adapt the configurator to a context where customer requirements constantly change and configurations need adaptations. As explained by company E: "*…Product configurator requires continuous* *improvement in terms of product design and configuration to serve our markets. Indeed, our customers often change their requests and the product configuration varies a lot. This is hard to manage while introducing a product configurator and it is a challenge that needs to be carefully addressed*".

Additionally, companies pointed out the challenges related to system management such as the need for timely updates, testing, and making the system user-friendly. For example, company C stated that: "*Once our system achieved maturity, we realized that a big still unsolved problem was related to the management of the product configurator. For example, we were not able to update our products variants and to automate the information flow between the customer and the company […] Additionally, after some time of usage, the system needed to be adjusted to make it easier to use. We wanted to create a simple and intuitive system, but it takes time and needs ad-hoc actions, also because the final aim is to make the customers use it directly*".

Table 6 summarizes the challenges underlined by the cases in post-implementation phase.

------------ *PLEASE INSERT HERE TABLE 6* ------------

5.4 Actions to face the challenges: the pre-implementation phase

The outcome of the case study research is shown in Table 7.

------------ *PLEASE INSERT HERE TABLE 7* ------------

The review of the product design, according to all the cases analysed, implies rethinking the product structure and working on design principles to solve the challenge of achieving both engineering efficiency and flexibility. Most of the ETO companies realized, over the years, that the only way to overcome these two challenges is to completely change the pillars on which their product design has always been based, particularly moving towards the platform-based and modularity concepts. This enables the cross usage of components, reducing unnecessary redundancy and exploiting economies of scale by sharing production activities between different products. For example, company G underlined that "…*In the past we created a lot of different technical drawings linked to very similar components. To implement the configurator, it is necessary to conceive our products based on their functionalities and defines the commonalities among them. Thus, we are changing the design of our products, developing modular components that are suitable to different products thanks to interfaces that are always the same*".

All the companies interviewed underlined the need for the redesign of the sales process, as well as the management of a different and innovative customer relationship, by standardizing of the order processing process through the translation of commercial languages into other languages (engineering and production) and the standardization and simplification of the technical coding that describes the products. This is considered to be a desirable practice when implementing configurators in an ETO environment because companies can easily automate the process and improve their efficiency and effectiveness in managing orders. Also, when this process is standardized and managed automatically by an IT system, it generates consistent data about customers' preferences that, in turn, allows companies to collect useful historical data to analyse and better develop new products. Through order processing automation, companies can put in place data mining methodologies and develop products following the exact market requirements. According to company B: "*We had the need to standardize the order processing before implementing the configurator to aid salespeople in rapidly adapting their work to the new tool. This brought a simplification of the technical coding: before, for each order, a new code was created - now it is already regulated and it is the same for the sales, engineering and* *production departments; this avoids proliferation of codes in the system and makes possible to rapidly translate the offer into an order. […] Also, not having standard and automatic order processing led to an incorrect communication with customers. We didn't have all the information under control and, so, we didn't convey messages towards customers in the right way. Through processes automation, resulting from product and information standardization, we have been able to improve our order processing: from 500 offerings in 2017 to 1,400 in 2018.*"

The cases also agreed on the need for the engineering process standardization, which consists of mapping all the activities carried out by the engineering department and dividing them into two groups: those that are always the same day-by-day and those that are different based on the order, which requires customization innovation, and maximum mental strain. The first ones can be standardized, and specific procedures can be related to them. This distinction, together with the standardization of documentation, helps companies in automating part of the engineering process through the configurator. This increases engineering efficiency and makes it possible to aid engineers in spending more time on the value-added activities related to customers' requirements for customization and innovation. For example, company D stated that "*We devoted an enormous amount of time to low value-added activities, because we designed from scratch the products that the customer requires, even if they were similar to previous ones. Thus, we started the standardization process. We began from the most critical activity, i.e., the electro-pneumatic system design. Each time we wasted more than two days designing the electrical diagram and its relative bill of material, even if we knew it was always the same. Now the documentation and the engineering process procedure is completely standard, so the design activities can be automated, saving a huge amount of time*".

As far as the production process redesign and the relationship with suppliers are concerned, not all of the cases provided interesting insights. Some of them underlined the importance of redesigning the production processes in terms of production flows, sharing the production resources among different products, and flexibility in the operations. Other companies implemented an information network and defined standards and rules within the supply chain. For example, company B shared the changes with all of its suppliers and defined a standard template where the list of all standard codes of product components were provided, asking to the suppliers to update periodically with new prices to automate in the configurator and the computation of the purchasing cost, making the sales process faster. Additionally, other companies (C and D) supported the idea that special contracts with suppliers might be necessary in order to define minimum quantities to purchase with a consequent cost reduction and the anticipation of the order to ensure responsiveness.

5.5 Actions to face the challenges: the implementation phase

The outcome of the case study research is shown in Table 8.

------------ *PLEASE INSERT HERE TABLE 8* ------------

Three main topics have been treated by the interviewed companies regarding the implementation phase: the knowledge acquisition, the configurator specification and development, and the organizational implementation.

5.5.1 Knowledge Acquisition: Make or Buy?

Given the importance of the IT aspect of product configuration and the challenge related to the lack of knowledge on product configurator structure and functionalities, this section will dive deeper into the implementation of software. Our case studies looked at this topic as a problem of "make" or "buy": in fact, certain companies developed the configurator internally, while others asked for the help of external consultants. The company should understand who will develop the product configurator and how, based on companies' competences. Company B exemplified the "buy" approach: "*We did not have the competences to internally create and develop the system and, thus, we decided to ask for help from an external software provider, who followed us for the entire development phase*". Initially, their product configurator was a module of their ERP, but they later decided to change this system and switch to two stand-alone software shells. In fact, according to their interviewee, the ERP system was very good, but "*if I have an excellent ERP, I have a code because of which the configurator will never be fast and easy-to-use for any salesman*". Another interesting remark, related to their collaboration with the consultants who implemented the new software, was that the consultants themselves learned something after the implementation project in company B, and later used this experience to sell new projects in other companies within the industry. In other words, there was not only a knowledge transfer from consultant to company, but also a knowledge exchange, which built new capacities and unleashed new opportunities for both parties.

Company E, instead, adopted the "make" approach: its configurator was developed by the IT department, and the only external support required was to integrate it with the ERP system of the company. The first noteworthy aspect of this choice was that it cut communication costs: "*…instead, in this way* [by developing the configurator internally], *we were much more flexible. If there had been something that we did not like, it would have been fixed within two days*". The second aspect was that the internal development directly involved the employees, increasing participation and thus reducing resistance to change.

Finally, in some cases, the organization opted for a "hybrid" approach and, hence, internal elaboration supported by external consulting. One example of this was company F: “*We realized that the competencies needed to develop the configurator are substantial, so we decided to ask for suggestions from an external software provider. However, we need suggestions only on the technical tool development, not on the technical specifications. Indeed, we want to configure the configurator, building the tool as we wanted*”. In short, product configurator realization is something that changes from context to context, mainly according to a company's competencies in terms of IT development capabilities.

A final interesting case was that of company D, which was an evolution from “make” to “buy”. Company D started with a full in-house approach, but it then realized that this required an excessive investment of resources. therefore, later, since the company introduced a commercial ERP system, which contained a configurator module, the decision was made to also rely on the ERP’s consultants for the configurator. However, the interviewee of company D stated that the work done in the first attempt, which apparently failed, was not lost, since at least the knowledge gained from the engineering effort could be re-used in the new project.

5.5.2. Configurator specification and development

The definition of the product configurator function is another element which companies must reflect on. The challenge of the lack of synergies between departments derived from a lack of a clear vision about the configurator’s future utility. Thus, for the project to succeed it is essential to establish a clear vision about the configurator, particularly ensuring that this system is consistent with company strategy, and to set clear project development milestones. According to company B: “…*When introducing a product configurator, it is important to have a clear vision regarding the configurator functions,* *otherwise the project could be driven by confusion and the risk of failure is high*". Also, according to some of the companies interviewed, sales and engineering departments should work together to ensure the alignment of both sales and engineering needs.

To overcome the challenge related to the fact that the product configurator needs data coming from all other IT systems, the company should also integrate the configurator with the existing IT infrastructure. This is a complex issue, not only because IT architecture review is complicated in any case, but also because if a company does not take this element into consideration in the right manner, it could lead towards the project's failure. According to company F: "…*During the introduction phase, the company should analyse in detail its IT infrastructure, for instance through an IT mapping, then it should understand what the most suitable solution is. It is important to make the right choice: either you delete all the previous systems and build all over again, or you try to integrate the new modules to the as-is situation. We chose the second option because the first one requires a long ramp-up phase*".

The reengineering of information flow is also important, as it allows the definition of how and to what extent departments will see configurator information and how these data can be exchanged. Thus, at this stage, it is essential to understand how to create standard but also complete information, because only in this way will it be possible for the data to travel easily without losing crucial knowledge, and how much visibility to give to each unit, particularly reflecting on the reasons for this decision. As company E explained, for example: "*"With the configurator, we wanted to create a link between the sales department and the rest of the company. Because when you receive an order, different departments must intervene. Firstly, the accounting department, then technical and purchasing office and finally production with planning. Thus, we needed to change* *the information flow, making it more efficient and open, but this took some effort but gradually augmented information visibility*".

5.5.3 Organizational Implementation

According to many of the companies interviewed, the adoption of a product configurator implies that senior management are strongly committed to the project in order for it to be successful from the outset. Additionally, the salesmen and engineers need to change the way they work. According to our case studies, employees are typically resistant to this change. For instance, company D stated: "*We noted that some workers, especially technical office ones, exhibited resistance to configurator's implementation. This is because the employees felt affected on their main competence as the company was removing something that for them is an added value*". However, companies that successfully implemented product configurators managed to overcome this resistance by adopting different managerial practices. After having reviewed the IT infrastructure, it is critical to reconsider the arrangement of the firm in terms of departments, functions, and tasks. In particular, companies have two interesting possibilities, as proposed, for example, by company A: "*The company should analyze whether it needs to create a new unit, completely dedicated to the project, or to simply commit some internal professionals, mainly belonging to the engineering and sales departments. Then, the company should clarify, on the one hand, who will manage the system, fixing the issues that arise; on the other hand, who will simply exploit it, seeing the product configurator as a sort of black box*". This decision depends on the competences owned by the technical and sales figures within the company.

Different interviewees agreed on the need to educate employees, i.e., making them capable to work with the configurator, but also to understand the reasons for and advantages of the change. In fact, as the director of engineering of company D stated, "*sometimes it is necessary to show the advantages of choosing a way that will actually bring you benefits from the work point of view*" since, as the area sales manager of company B said, employees have a "*cultural problem, meaning that if you make them understand that life can improve, then it will improve*". In this sense, company F adopted an interesting tool to sensitize employees: their internal magazine, "*Smart News*", which was used to promote the configurator within the company.

Another commonly adopted approach is participation: "*talking, meeting together, actually understanding what the company wants, involving people works*", as an interviewee of company B said. In particular, company B stressed the importance, during the pre-implementation phase, of involving people who are trusted by their colleagues because of their technical expertise, e.g., the person who is considered the "*mage of IT*" in his office. These employees can become "*agents of change*" or, to use another well-known term in the change management literature, "champions" (e.g., Barker et al. 1989). In general, participation seems to be particularly helpful in overcoming the distrust of the most technically prepared people. In fact, when the sales director of company E was asked whether the engineering team resisted change, his answer was negative, "*because we used solutions that they developed*".

Although we did not find evidence of the adoption of facilitation and negotiation practices, interviewees from companies B, D, and E mentioned coercion. In fact, as the sales manager of company B observed, employees may have different levels of openness to change, and the most resistant ones may need to be obliged: eventually, "*when the boss says you must do it, you do it*". However, it seems that coercion should be sought only when all other approaches have failed: as an interviewee of company D said, "*at the end of the day, the company is made up by people, and you cannot say to a person: you are forced to use it*" [the configurator].

5.6 Actions to face the challenges: the post-implementation

The outcome of the case study research is shown in Table 9.

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According to our case studies, the actions employed to face the challenges in the post-implementation stage can be grouped in to two main categories: the simple maintenance of the configurator on the one hand, and its upgrading on the other.

5.6.1 Maintenance

Product configurator management is an important action that pertains to system maintenance. In fact, actions should be put in place to assure the proper alignment to product and process changes. Indeed, like all the other IT systems, a product configurator needs to be continuously maintained to work well, especially in seeking to comprehend the ways in which immense amount of data that this software receives and generates should be managed. In this regard, the traceability concept is essential. At this stage, the company should develop automatic control and supervision systems inside the product configurator to avoid as many human mistakes as possible during the configuration process. According to company C: "*Automatic control systems can help in defining some constraints of the system: in this way, if an employee forgets to insert some data, the software blocks the whole configuration process*".

Another important set of actions is related to the continuous improvement of the system. The company can achieve this purpose in different ways, mainly depending on its culture and product configurator type. For instance, company C stated that: "*We ask for customers' feedback since our product configurator is web-based. Thus, all clients can use it and can provide suggestions to improve the system*".

Lastly, human resources management actions have the task of overseeing the relationship between the product configurator and the people whose role it is to exploit it, by assuring that the system is user-friendly for all the departments involved in its use. At this stage, the company also needs to take care of issues such as the potential lack of commitment of the employees, who might refuse to adopt the new way of working. In this case, the company must immediately act to eliminate this feeling, and there are several ways to do it: management can show the benefits that the company might gain by using the system, exploit interpersonal relationships, or raise awareness that in the very near future it will be prohibitive to do certain jobs manually. For example, company E explained that: "*We know that the configurator can have a devastating effect on people and processes if we do not solve problems when they appear. What we do is to share problems, solutions, results with all our collaborators by organizing periodical meetings to collect feedback from the users. This is the best instrument to point out the direction in which the company is moving. We want to show that we are investing in that direction because there are some benefits to gather*".

5.6.2 Upgrading

According to the results of our case study analysis, companies that successfully managed their product configurators did not just "maintain" them, but rather they "upgraded" them. In fact, after the implementation, they had to modify their configurators in order to manage new products, new variants, or new components. More specifically, we observed two product configurator upgrade approaches: one can be called "comprehensive", while the other can be defined as "focused".

In the comprehensive approach, a configurator, whose initial potential product range was very broad, is modified so that its growth is limited. This approach can be inexpensive, especially if the required modifications are easy to implement; however, the company may lose track of the items excluded from the configurator.

In the focused approach, instead, a configurator, whose initial potential product range was quite narrow, is allowed to grow in an unlimited way, while the company defines a different pipeline to manage the part of its product variety left out from the existing system. This approach may be more expensive than the previous one: the first reason is that adding an increasing number of codes is time-consuming, although this depends on the features of the configurator; the second reason is that managing the products left out from the existing configurator may absorb a high amount of resources. In fact, the company may even decide to create two configurators, which would, however, require a noteworthy investment.

Company B exemplifies the comprehensive approach. Company B has one software platform for the sales configurator and another for the technical one. The two platforms are linked together. The potential product range managed by them is very broad: "*given 100 offers, at the end of the day only 10 are those that you need to modify a bit. So you can actually cover the 90% of the cases*", stated the area sales manager. In the first month of the post-implementation phase of the sales configurator, company B kept expanding it by adding an increasing number of components. Hence, a "*total proliferation of [product] codes"* was allowed, as stated by the area sales manager. However, "*the need to make the two systems communicate*", which requires a complex process, made it difficult to introduce new codes. Therefore, at a certain point, the company decided to limit the growth of the range managed by the configurator by introducing so-called "jolly codes". In short, jolly codes are approximately 20 "*empty codes*", one for each macro-part of a product, which can be used to manage the customizations that a client may require for that specific part without the need to create a brand new code on the configurator. Jolly codes are used for requests, usually made "*just one or two of times per year*": basically, this is either the case for products which need a "*strong customization*" (i.e. major modifications), or products that require only minor modifications, e.g., when "*the client asks for a blue line*", or when "*the client asks for a star-shaped extruder*". According to the interviewee, the IT system also offers the possibility to keep track of the jolly codes. For example, at the end of the year, it is possible to know which were the most frequently asked modifications and, only then, codify them on the configurators.

Company E, instead, exemplifies the focused approach. Similarly to company B, company E receives orders with different degrees of customization. Certain orders can be easily satisfied by combining previously defined modules: as the sales director pointed out in an interview, the configuration process starts with a "*minimal configuration*" or a "*naked machine*", to which, with a "*growing procedure*", different devices are gradually added. However, there are also orders which require modifications to the components; for instance, there are certain "*tools*" that always need to be customized. Differently from company B, company E *"created, in the configurator, the freedom to add components – called non-standard – defined and priced time after time, and for which the more detailed the description was, the easier the life for who was supposed to develop the machine"*. Therefore, the configurator of company E continued to grow each year. The interviewee was also asked whether any salesman or technician ever wanted to "*clean*" the oldest codes, but his answer was negative. In fact, he said that this approach allowed the company to save the "*experience*" accumulated during each project, which could be beneficial to simplify future designs and speed up the quotation process. Moreover, the sales director stated that, in the future, they aim to develop a second configuration, maybe with more flexible functionalities, to manage highly customized orders; for instance, by supporting employees in the identification of similar past projects that simplify the pricing process.

Another interesting case is the one of company D. Company D has two product lines: "*entry-level*" products, which are easier to standardize, and "*tailor made*" products, which require a higher level of engineering effort. At the moment, the scope of the configurator that company D aims to develop includes only entry-level products. Therefore, this seems to be a starting situation similar to that of company E. However, company D aims to develop a configurator that, in the future post-implementation stage, will have some functionalities useful also for tailor-made products. For instance, as the sub-components of tailor-made products already have well-determined costs, they will be imported on the configurator to guarantee uniformity for all salesmen around the world. Moreover, in the post-implementation phase, the configurator will be allowed to identify these sub-components with a "*fictitious part number*", similar to the way in which company E uses jolly codes.

6. Discussion

As anticipated in the introduction, this paper aims to answer the following research question: *How do ETO companies overcome the challenges faced before, during, and after product configurator implementation to enable mass customization?*

The analysis of the results of the multiple case study research led to achieve this aim by investigating the product configurator implementation projects of the companies studied. The case companies underlined that the implementation of a product configurator can be an enabler for mass customization, which is supported by several publications (e.g. Haug, Hvam, and Mortensen 2011; Duchi et al. 2014). However, some challenges must be considered, along with the actions to face them. These challenges were analysed and presented in a comprehensive way by Haug et al. (2019a), which proposed a set of general guidelines that can support companies in overcoming these issues. Our work is built upon such study and consists in a set of detailed actions that can be used by companies to put in practice the guidelines mentioned by Haug et al. (2019a). In this sense, Tables 7, 8, and 9 show the main results obtained from the case studies. Interestingly, it can be noticed that one guideline proposed by Haug et al. (2019a) can be translated in more than one practical action.

Specifically, in the pre-implementation phase (see Table 7), companies provided further details on the possible actions that can be undertaken to perform a product design revision, such as the application of a platform-based approach and of the modularity concept. Furthermore, interviewees underlined the need for making the knowledge more accessible, on the one hand, and for redesigning the processes, on the other. As far as the former aspect is concerned, the study showed that the key actors to manage the knowledge sharing can be both internal and external to the company, namely the sales, engineering, and production departments, as well as the subcomponent suppliers. The complete visibility of relevant product information should be ensured among them, through the standardisation and simplification of the knowledge base, the agreement on a common language, and the establishment of a structured documentation. As far as the redesign of the processes is concerned, instead, companies underlined the need to include in the redesign also engineering – a core process for an ETO company – by enhancing process standardization and including procedures related to the most repetitive design activities. Moreover, the case studies highlighted the importance of redesigning not only the sales process, but also the production process and the purchase one: in short, all the key processes and actors should be aligned to the transformation brought by the configurator. This aims to overcome the initial barriers due to a misalignment of goals, missing information, and lack of resources.

In the implementation phase (see Table 8), the case studies employed two different actions to put in practice the guideline by Haug et al. (2019a) related to applying a structured plan to acquire, communicate and maintain the knowledge. Specifically, our case studies highlighted the importance of the “make or buy” problem, since certain companies developed the configurator internally, while other ones asked for the help of external consultants, and other ones adopted a hybrid approach. Another guideline to be followed in this phase is reaching an agreement on the scope of the project, and the actions to put it in practice are related not only to a structured and inclusive approach to the company’s strategy and project, but also to the management of the interfaces between different departments, as knowledge exchanges and common meetings must be performed. For the configurator specification and development, the cases confirmed the importance of properly integrating the configurator with the existing IT structure, but they also stressed the need to consider the remarkable changes that the configurator will bring to the information flows in general, and discussed how to include them into the IT infrastructure: the new configurator should be designed by taking into account the constraints of the IT systems, but IT systems may need changes and revisions according to the needs of the configurator. Finally, our study confirmed the relevance of redesigning the roles within the organization. In short, for what concerns the organizational implementation, the words of the interviewees corroborate the well-known framework by Kotter and Schlesinger, who identified five main methods for managing resistance: education, participation, facilitation, negotiation, and coercion (Kotter and Schlesinger 2008).

In the post-implementation phase (see Table 9), Haug et al. (2019a) suggested documenting the changes made during the configurator development, continuously ensuring the user support, and fulfilling changes in the user demands. For what regards the first guideline, our case studies showed the key role that can be played by the automation of control and supervision systems to support the proper documentation of changes. Concerning the second guideline, the case studies showed two main ways of involving users and guaranteeing their support along the configurator lifecycle: continuous engagement and feedback collection. Finally, two main approaches to "upgrade" the configurator in order to fulfil the changing demands of the user base emerged: a "comprehensive" approach, i.e. when the possibility to add new codes into the configurator, that at the beginning already included a large set of products families, is voluntarily limited, – cheaper, but with a potential loss of information – and a "focused" one, i.e. when the number of codes inserted into the configurator, whose initial potential product range was quite narrow, is allowed to grow in an unlimited way – which, conversely, may require higher resources but, eventually, it may allow the company to have a richer knowledge base.

7. Conclusions

In conclusion, this study meets the purpose of filling the gap identified in the literature, as few studies have systematically explored the actions to overcome the challenges that ETO companies face when implementing product configurators to enable mass customization. Therefore, this work enriches the current ETO literature, as it provides the empirical observations of cases that successfully reached different implementation stages of product configurators. This allows researchers to confirm the previous studies and acquire a better understanding of the topic, thanks to further details and insights. This study also improves the description of the possible solutions that ETO companies can employ to face the issues related to the shift from ETO to mass customization, a topic considered important but still understudied in the literature (Sandrin, Trentin, and Forza 2018).

Moreover, from a pragmatic viewpoint, the existing literature merely gives hints concerning configurator implementation projects and, thus, managers might find difficulty in effectively implementing this system. This research analysed 7 case studies that practically show how to prepare a successful implementation of a product configurator, which requires to first and foremost redesign products, processes, and relationships with customers and suppliers, so to support the change in an effective way, and avoid to be caught unprepared. Furthermore, the results show practical examples of solutions to acquire knowledge during the implementation, as well as how to develop the configurator and how to guide the change from an organizational viewpoint. Finally, useful insights are provided regarding the post-implementation, where the maintenance and upgrading of the configurator are necessary. In particular, this study contributes to the practice by providing an empirical-based tool to identify the multiple strategies to face the challenges in the different phases of product configurator implementation project, and apply the guidelines previously proposed by the literature. Specifically, in tables 7-9, each manager of an ETO company can see the multiple opportunities for successfully framing the product configurator implementation project.

This study also presents some limitations, which represent interesting starting points for further research. First of all, the presented challenges are listed and not ranked. To provide managers with suggestions for prioritizing managerial actions to manage the challenges, future research might start from the developed list to investigate importance and probability of occurrence of the challenges in different projects contexts. Moreover, this study applies a qualitative method, which is considered an effective methodology for an in-depth understanding of phenomena thanks to the direct observation in the natural setting of the participants, but very difficult to be generalized (Babbie 2013). Indeed, although the research has been designed to be as valid and reliable as possible, the population studied cannot be as large as the ones addressed by quantitative studies. Therefore, future studies are invited to address this research topic by applying quantitative methodologies, in order to obtain a statistical validation of the findings and increase their generalizability. Given the high importance of “buy” solutions in product configurator implementation projects, another interesting future research direction would be to study the same issue from the perspective of consultants and software providers, since – to the best of our knowledge – little research has been carried out on this aspect. Finally, further research may also consider the synergies between product configurators and other “Industry 4.0” technologies, as they are currently reshaping the manufacturing industry and have the potential to move more and more companies towards the mass customization paradigm.

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Table 1. Case studies overview

Company name	Turnover (2018) [k€]	Number of Employees (2018)	Sector	Interviewee
A	53,784	274	Helicopters, aeronautics, defense systems	Chief product engineer and Interior design responsible
B	114,800	192	Complete extrusion lines for packaging and converting	Top manager and sales manager
C	938	18	Geared motors, industrial gearboxes and worm gears	Sales manager
D	10,285	37	Ink dosing machines	Technical manager
E	91,610	316	Winding and assembly systems for coils and motors	Sales manager
F	12,735	69	Systems and machines for production process automation	Special projects and innovation manager
G	90,450	315	Boring-milling machines and machine centers	Technical manager

Table 2. Case study protocol

Source 1: face-to-face interview (at least 2 interviews and at least 3 hours per each case)	
General information	Interviewed brief description: Role played inside company and department affiliation; Tasks carried out; Company description: Overall: revenues, size, number of employees and internal organization; Industry key characteristics and success factors; Company's products; Markets and competitors
Product configurator characteristics	Main features of the product configurator Type of product configurator and applications
Pre-implementation phase	When did the configurator's implementation project begin? What were the main motivations that pushed the company to implement this system? For what concerns the scope of the configurator, did the company decide to implement the system for one product / a narrow set of products or immediately for the entire product portfolio? Why? How did the managers revise the business processes of the company? How did the managers modify the designs of the products? How did the managers prepare the organization for the configurator? What were the main challenges encountered during these phases? How did the company overcome these challenges? Did the company prepare its suppliers or its customers to the usage of the configurator?
Implementation phase	At the beginning of the project, did the configurator appear to be as a too complex system to manage?

	Did it require high technical skills to be used correctly? How has the company decided to develop these skills? Has the company decided to assume new staff from outside or to exploit existing internal resources? Did the configurator find resistance from the employees? If yes, how did the company manage such resistance?
Post-implementation phase	Did the configurator require maintenance? Of which type? How were new products included in the configurator? How did the configurator change the relationships with the suppliers and the customers?
Source 2: Direct observations (at least 1 hour per each case)	
Plant tour	Direct observation of the configurators and their applications in the sales and/or engineering and/or production processes. Additional observations of the sales, engineering and production department during working shifts with the possibility to watch activities and ask additional questions to the employees and/or managers related to the products, the processes, and how the configurator supports this.
Source 3: Official documents	
Company's website	General company information (history, strategy, mission, etc.); Product range (product types, product features, technical data, applications, etc.).
News and press	Up-to-date information related to new products introduction.
National database	Public information on financial data: balance sheet and number of employees.

Source 4: Internal documents	
Documents (digital or paper)	Project plans, product catalogues, etc.
Information systems	Technical description of activities performed by the configurator, presentations of the features of the product configurator, software demo.

Table 3. Configurator projects in the case companies – quotations from the case studies

Case company	Sales Configurator	Technical Configurator
A	None	*"We have a technical configurator. Mainly, it is an interior 3D viewer that we use to design the helicopter[…]. We especially use it to understand if what we are selling is feasible, for instance, if the different parts are compatible between them, and what is the final cost for us. So, we use this system in the back-offices and not during the sale phase […] When the helicopter is sold, the configurator starts the production process, explaining how that machine is composed and what are the parts to manufacture"*
B	*"We use our configurator during the negotiation with customers, to be able to express the available technical solutions, the options that are compatible with them and their relations. Thus, we take advantage of this system to create the commercial offering"*	*"What we are trying to do (and, at the moment, we have done it for some things, for other things we are still behind) is to have a higher correlation between commercial code and technical code, so to go directly to the machine level"*
C	*"Through the configurator, we automate the order processing phase and the technical documentation creation phase. So, the units affected by the configurator are sales and engineering departments […] After having received system's configuration form the customer, the configurator is able to automatically generate technical documentation to send to the distributors, such as 2D technical drawings, assembly schemes and bill of materials"*	
D	*"Our idea is that sales representatives use the configurator when they have the first meeting with customers. It is a very simple tool, easy to use, through which they are able to define the machine and, then, it automatically sends this information to the company management system"*	*"Our configurator takes as inputs the machine characteristics, thus the components' number and size, the system type, namely if it is water or solvent-based, the automation level etc. Then, it generates automatically some outputs that are the wiring diagram and the mechanical layout with the respective bill of materials. These outputs are directly received by the operations"*

<table>
<tr><th>Case company</th><th>Sales configurator</th><th>Technical configurator</th></tr>
<tr><td>E</td><td colspan="2">“When we have the first meeting with the customer, our sales representatives create the machine through the configurator. The customer says the number of coils that it wants to realise, so the production capacity and our sales representatives calculate the mandrel's number and configure the machine, sharing with the clients all the different possibilities. In short, their job is to transform the customer's request into a machine configuration, that should be the as much logical and competitive as possible […] Then, this configuration arrives at the engineering office, that puts together all the part codes and generate the bill of materials. When this transition is done, these codes are transformed into other codes necessary for the purchasing department. Some of these components are standard and thus we can buy them in big quantities, while others are specific equipment and we acquire them from time to time […]Our configurator is able to directly transmit the machine configuration to the production, so that, once the machine is defined with the customer, manufacturing system is able to start having the bill of material at the disposal”</td></tr>
<tr><td>F</td><td colspan="2">“We are developing the configurator with this concept: the starting point is a database, made up of different single modules. What we can do to create an offer to our customer is to use this configurator and simply select the different station types that we need to complete the entire machine. Our vision is to make the configurator work in two different contexts: firstly, to configure the product in front of the client, to quickly generate an offer and to give her/him a price idea; secondly, to create the internal offers and documentation, necessary for the resources supply”</td></tr>
<tr><td>G</td><td>“We use a commercial configurator in our processes now. However, until this time, we can’t directly translate order’s information into technical documentation, such as the bill of material necessary to start sourcing and production processes. We tried to make this link in the past, but we had issues in translating commercial aggregated information into technical specific ones”</td><td>None</td></tr>
</table>

Table 4. Challenges faced by the case companies in the pre-implementation phase

#	Challenges in the pre-implementation phase	Case studies						
		A	**B**	**C**	**D**	**E**	**F**	**G**
	Product (re)design							
1	The product should be designed to meet a wide set of different customers' requirements (to assure the flexibility required by the ETO market)	X						
2	The product should be designed in order to exploit design commonalities with past projects and already existing designs				X	X	X	X
3	The product should be designed in order to minimize the complexity and avoid "paradox of choices"	X		X	X	X		X
	Sales process (re)design							
4	Need for sales departments to be aligned with the engineering one through continuous exchanges so to support salespeople in configuring the product consistently with engineering needs		X		X		X	
	Engineering process (re)design							
5	The engineering process should be (re)designed to allow anticipation of some activities before the customer order arrival	X		X	X	X	X	X
6	The engineering process should be (re)designed to allow automation of some engineering activities	X	X	X	X	X	X	X

	Production process re(design)							
7	The production process should be (re)designed to face the increased production volumes	X		X	X	X		X
8	The production process should be (re)designed to maintain the production flexibility required by the ETO market		X	X	X	X		
	Supplier relationship management							
9	Suppliers should assure the production flexibility required by the ETO market			X	X			
10	Suppliers should be able to absorb higher volumes				X	X		X
11	Suppliers should be open to collaboratively (re)design the products			X				
	Customer relationship management							
12	The company should be able to anticipate customers’ requests before the order	X	X	X	X		X	
13	The company should group customers’ requests into a product catalogue	X	X		X		X	X

Table 5. Challenges faced by the case companies in the implementation

#	Challenges in the configurator implementation project	Case studies						
		A	**B**	**C**	**D**	**E**	**F**	**G**
	Implementation phase							
1	Lack of know-how related to the product configurator structure and functionalities and need for competence upgrading	X	X	X		X		X
2	Lack of synergies between departments and need to extend the technical knowledge related to product configurators between departments	X	X	X	X	X	X	
3	The product configurator needs data coming from all the other IT systems inside the firm and/or the IT systems of the external partners, and vice versa		X	X		X	X	
4	A Business Process Reengineering is needed to establish new processes, new tasks, change the personal roles, define procedures	X	X	X	X	X	X	X
5	Resistance to change	X	X	X	X	X	X	X

Table 6. Challenges faced by the case companies in the post-implementation phase

#	Challenges in the configurator post-implementation	Case studies						
		A	**B**	**C**	**D**	**E**	**F**	**G**
1	Risk of misalignment between the configurator and the data of newly developed products			X	X	X		
2	Risk of human mistakes during the configuration process			X		X		
3	Possible resistance to change from the employees			X	X	X		
4	Risk of low user friendliness of the configurator			X		X		
5	Risk of excessive proliferation of product codes			X		X		

Table 7. Actions adopted by companies to face the challenges of the pre-implementation phase

Guideline from Haug et al. (2019a)	**Detailed actions**	**Case studies**							**Challenge(s) faced *(See Table 4)***
		A	**B**	**C**	**D**	**E**	**F**	**G**	
	Product (re)design								
"Investigate whether products need to be redesigned to become more configurable"	Review of the product design moving towards the platform-based by identifying commonalities among products based on their functionalities	X	X	X	X	X	X	X	1,2,3
	Change of the product design applying the modularity concept	X	X	X	X	X	X	X	1,2,3

	Sales process (re)design / Customer relationship management								
"Ensure that knowledge engineers have or have access to the needed product expertise"	Standardization of the order processing process through the translation of commercial languages into other languages (engineering and production)	X	X	X	X	X	X	X	4,5,6,12,13
	Simplification of the technical coding by reducing the proliferation of codes and	X	X	X	X	X	X	X	4,5,6,12,13

	unifying products codes								
	Engineering process (re)design								
"Carefully investigate if the […] processes are suitable for configuration"	Standardization of the engineering process by creating specific procedures related to the repetitive design activities	X	X	X	X	X	X	X	4,5,6,12
"Ensure that acquired knowledge is well documented"	Standardization of the documentation associated to the product specifications in accordance with the sales	X	X	X	X	X	X	X	4,5,6,13

	and production needs								
	Production process (re)design								
“Carefully investigate if […] processes are suitable for configuration”	Sharing of production activities between different products	X			X	X			7,8
	Review of the production process and facilities to enhance flexibility				X				7,8
	Supplier relationship management								
“Carefully investigate if […] processes are suitable	Enhance information sharing along the supply chain		X	X					9,10,11,13

for configuration”	Definition of standards and rules within the supply chain		X	X					9,10,11,13
	Anticipation of the order to the supplier through special contracts			X	X				7,8,9,10,11,13

Table 8. Actions to face challenges in the configurator implementation project

Guideline from Haug et al. (2019a)	**Actions**	**Case studies**							**Challenge(s) faced *(See Table 5)***
		A	**B**	**C**	**D**	**E**	**F**	**G**	
	Knowledge acquisition								
"Apply a structured plan to acquire, communicate and maintain the knowledge"	The company can develop the configurator internally, partially supported by external IT consultants			X	X	X	X		1, 4
	The company can buy a configurator shell particularly in line with company needs	X	X		X		X	X	1, 4
	Configurator specification and development								
"Ensure agreement on the scope before	The company should define the	X	X	X			X	X	4

initiating knowledge acquisition”	product configurator consistently with the company strategy								
	Sales and engineering departments should work together to assure alignment of both sales and engineering needs		X		X		X		2
“*Do not raise budgets before carefully examining the realism of promised deliveries*”	The company should identify project development milestones	X	X	X			X	X	4
“*Consider the necessary interfaces to other systems*”	The company should integrate the configurator with the already existent IT infrastructure		X	X		X	X		3

	The company should redesign information flows, i.e. define how and to which extent departments will see configurator information and how to exchange these data		X	X	X	X	X		2,4
	Organizational implementation								
“*Ensure that managers will support the process in the future*”	Top management should be strongly committed to the project		X		X	X	X		4,5
“*Be aware of the organisational changes, especially for long-lasting projects*”	The company should redesign internal organization in terms of company departments roles	X		X	X	X	X	X	4
“*Ensure adequate resources for training users*”	The employees should be trained to overcome the lack	X	X	X		X	X	X	4

	of know-how related to the product configurator structure and functionalities								
“*Ensure that configurator maintenance and further development can be carried out by multiple employees*”	The employees should be trained to gain flexible skills in terms of configurator use and maintenance		X		X	X	X		4
“*Ensure adequate efforts to get users to support the configurator project*”	The employees should be trained to overcome the lack of know-how related to how the configurator would support inter-departments communication	X	X	X	X	X	X		2,4
	The company should reflect on		X		X	X	X		5

	possible additional training and/or specific events to overcome the resistance to change								
	The company should educate the employees, making them aware of the reasons and the advantages of configurators		X		X		X		5
	Employees should participate to the change process related to the configurator		X			X			5
	The most resistant employees should be obliged to accept the change		X		X	X			5

Table 9. Actions adopted by companies to face the challenges of the post-implementation phase

Guideline from Haug et al. (2019a)	**Actions**	**Case studies**							**Challenge(s) faced *(See Table 6)***
		A	**B**	**C**	**D**	**E**	**F**	**G**	
	System maintenance								
"Ensure that changes made are properly documented in the knowledge base, as it may otherwise be extremely difficult to update"	Development of automatic control and supervision systems to avoid missing data, errors and duplications when inserting and changing information in the knowledge base			X		X			2
"When necessary, continue efforts in making users support the project"	Early problem detection by collecting feedbacks from the users and/or the customers			X		X			4

	Continuous engagement of the employees to overcome their resistance			X		X			3
	System upgrading								
“Ensure that user change demands (changes and additions) can be fulfilled”	The company can limit the proliferation of the new codes by the use of a comprehensive approach, thus allowing only to add a limited number of new codes			X	X				5
	The company can allow the proliferation of the new codes for a specific product family that is managed with the configurator				X	X			1

	The company can develop of a second configurator, with different characteristics, to manage a different part of the product mix				X	X			1,5