New complex product introduction by means of product configuration

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Abstract

Configuration systems have widely been applied to efficiently address the customization responsiveness squeeze of companies dealing with Mass Customization. Over time, several frameworks have been introduced to enable their systematic planning, analyses, development and implementation. Traditional research has thereby either focused on defining modelling techniques for the configuration model of stable products, on improved configuration algorithms, or on the impact of configurators on companies' operations. However, little attention has yet been paid how the growing need for product innovation can effectively been supported. Especially for engineering companies moving towards Mass Customization, compared to mass producers the challenges caused by the complexity of their products and by the highly uncertain markets are much higher. This study develops and validates a framework which enables the use of configuration systems along the introduction of complex products. It in particular examines (1) what are suitable development strategies for configuration systems during product innovation, (2) how product development and configuration development can be aligned and managed, and (3) how supplier integration can be achieved.

1 Introduction

1.1 Background

With mass customization (MC) companies are aiming at effectively addressing the customization-responsiveness squeeze, i.e. the necessity of offering custom tailored products at nearly mass production efficiency [Tseng *et al.*, 2001]. Since its introduction in the late 1980's [Davis, 1989], the concept has received much attention from both practitioners and scientists. General strategies and advanced IT systems, such as configuration systems (CSs), have potentially helped companies to effectively cope with global competition and increased customer demands [Salvador *et al.*, 2009].

1.2 Motivation and outline of the paper

While much of the research has yet focused on developing models and theoretical frameworks, little empirical studies have explained the effective introduction of new customized products [Slamanig *et al.*, 2011]. Notably the use of configuration systems has seldom been discussed in the context of radical innovation processes [Hara *et al.*, 2012]. Thus considering the challenges of dynamically changing markets and increasing product complexity [Blecker *et al.*, 2006], further guidance based on empirical evidence is needed. Especially for engineer-to-order (ETO) manufacturers who are moving from an individual customization to a partly MC these challenges are particularly important. Compared to mass producers, their products are typically more complex and high uncertainties of demands make planning activities more difficult [Rahim *et al.*, 2003].

The emphasis of this study is therefore to investigate how new products can be launched effectively in situations in which product complexity (internal complexity) is rather high and where only little information about the customer requirements (external complexity) exists. A particular attention is thereby paid on how CSs can support product innovations for significant product renewals.

Based on a literature study (Section 2), the paper first examines existing approaches for MC with regard to the use of CSs in the context of new product introduction. Relevant frameworks are adapted to better meet the requirements of ETO manufacturers pursuing MC strategies and product innovation with product configuration (Section 3-4). Next, the newly introduced framework is applied on an industrial case study (Section 5), where a configuration model was initially developed. The achieved findings and practical implications are eventually discussed (Section 6).

2 Literature Review

2.1 Product configuration and mass customization

Offering bespoke products to customers affects the entire product realization process starting from the order acquisition to the order fulfilment [Forza and Salvador, 2002]. According to Jiao and Tseng (2004) the impact of customization can be described with the generic domains of an organization [Jiao and Tseng, 2004], where to begin with customer satisfaction can be achieved through the efficient match of the requirements to the offered solution space of product variants. Salvador et al. (2009) refer to this process as assortment matching, in which suitable software helps to link the existing solution space to customer's needs [Salvador *et al*., 2009]. The most common software systems that enable the realization of an efficient assortment matching are configuration systems [Forza and Salvador, 2002]. Being a subtype of a knowledge-based expert systems, CSs formally represent the product knowledge relevant to the customer (product features), allowing a complete definition of possible product outcomes (customized functional features) with a minimum of entities [Hvam *et al*., 2011].

More recently, researches have investigated the use of CSs not only as sales tools, but also in support of the entire specification process, i.e. the order acquisition and order fulfilment process [Forza and Salvador, 2002]. Helo *et al.* (2010) for instance propose a business model for the use of configuration systems throughout the entire specification process of a product [Helo *et al.*, 2010]. The authors discuss how sales configuration can first be used to translate customer needs into functional requirements of a product. In the physical domain, product configuration then matches the chosen set of functionalities into design parameters. Even though not implemented in the study, process configuration can eventually be used to select on a high level suitable production and logistic steps for the subsequent processes. Figure 1 below illustrates a generic value chain of a manufacturing company including its specification process. Depending on the scope of the project, CSs can potentially be implemented to support wholly or only partly the specification process [Hvam et al., 2008].

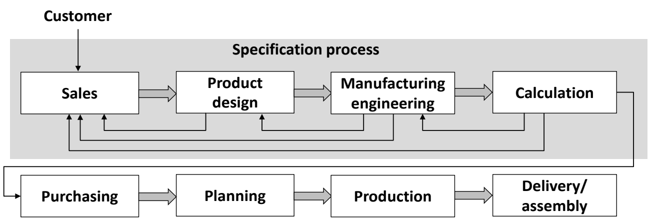

Figure 1: Generic specification process

2.2 Recent trends in product innovation

Obviously, by integrating the different customization domains into the configuration process helps to provide salesmen with more accurate estimations of time and cost of existing products. However, over time competition forces firms to update their established product portfolio. Smith et al. (2012) discuss two major reasons for companies to regularly work on product innovation:

1. customers change requirements, and
2. product performance needs to be constantly improved [Smith *et al.*, 2012].

Hence, in the first case new products are only introduced when considerable large discrepancy exists between customer needs and the provided functionality of existing products. In the latter case new ideas and technologies keep customers engaged with the products and thus stimulate sales [Howard *et al.*, 2011].

In majority of the cases, working on product innovation is typically based on existing products, where often more than 70% of the development tasks are related to redesigning, improving, and extending the products offered to the market [Ullman, 1997]. To achieve high productivity in the innovation, companies are on the one hand pressured to employ adequate tools and methods that allow an in-depth understanding and managing of knowledge related to products, processes, as well as to their project environment [Vezzetti *et al.*, 2011]. On the other hand, to compete on dynamically changing markets, it has become essential to transform the innovation process from a linear to a spiral model with short and direct iterative loops and feedback cycles [Cooper and Edgett, 2008]. By doing so, initial ideas and prototypes are immediately tested, where early feedback is used for further development [Salvador *et al.*, 2009].

As technology is progressing and being used in more and more areas of business, recent studies demonstrate that a high level of technical assessment in innovation significantly improves companies' business performance. With the use of advanced technologies, probable solutions, risks and potentials can initially be evaluated. Moreover, when considering the costs and benefits from suitable technology in early stages of the innovation process, the need for technology alliances can upfront be detected [Cooper and Edgett, 2008].

2.3 Product configuration, innovation and vendor collaboration

Despite configuration systems are playing an essential part in the customization process of manufacturers, in academia their use has typically been limited to streamline specification processes of matured and well established products, usually offered by one vendor [Blecker *et al.*, 2006; Hvam *et al.*, 2008; Forza and Salvador, 2008]. Forza and Salvador (2002) for example discuss the use of a configuration system in support of the order acquisition and fulfillment process of products from one vendor with high but relatively simple product variety [Forza and Salvador, 2002]. Hvam et al. (2006) argue for the use of configuration systems as a way to improve the quotation process of ETO products or even systems. By calculating budget quotations, the configuration system manages to create sufficiently precise price estimations offered by one company [Hvam *et al.*, 2006]. Also Haug et al. (2012) investigate the use of CSs in several manufacturers of rather complex and engineering intensive products. The authors illustrate the employment of different CS development strategies in support of specifying the existing product portfolios [Haug *et al.*, 2012].

Wang et al. (2009) introduce a framework for assessing configuration changes of exiting products. Based on the operational performance of suppliers, a generic algorithm is used to calculate how a changed part affects the preference for individual suppliers. The framework is exemplary tested on a simple electronic device. Even though the authors include the collaboration of several vendors into their framework, stable products with only minor product changes (different product variants) for relatively simple products have been examined [Wang *et al.*, 2006]. Ardissono et al. (2003) propose a theoretical framework for the use of a web-based configuration system which strives to enable the collaboration between different vendors. The authors however omit to explain how the CSs should be used in praxis, especially with regard to complex products and radical innovation [Ardissono *et al.*, 2003].

3 Research Design and Objectives

From reviewing the literature it can be stated that none of the mentioned case studies considers how CSs can be used in the cause of innovation and evolvement of a complex product family, in particular not together with the coordination between different suppliers or vendors. At the same time, prevailing on increasingly competitive markets requires efficient innovation processes which are flexible enough to quickly adapt to a fast changing environment [Cooper and Edgett, 2008]. This study therefore aims at developing a framework which addresses the dilemma of being innovative on dynamically changing markets and yet still efficiently providing custom tailored products. In order achieve practical validity, a case study with a company is performed. The collaboration is organized through action research where the researchers were actively involved in a transformation process [Coughlan and Coghlan, 2004]. The industrial partner is a start-up company, a contractor with a strategic collaboration with several ETO companies.

Already at an early stage of its establishment, the company has realized the potential of using advanced IT technologies and a well thought marketing approach to gain a competitive advantage within its industry. The alliance with the strategic partners enabled sharing the otherwise unreasonable IT investment and the related financial risks. At the same time, such a strong collaboration facilitated the exchange of knowledge concerning the products and potential market segments. Rigor of data was insured through foregoing interviews and through a series of short action research cycles conducted in the cause of twelve months.

4 A Procedure for Implementing Complex Product Configuration in NPD

Several frameworks for the development and implementation of CSs exist in literature. For the study at hand, a widely used and well-structured seven phase procedure introduced by Hvam et al. (2008) was chosen. The procedure is based on the object oriented project life cycle (analysis, design, implementation and maintenance), and further contains methods for analyzing product ranges as well as the related business processes [Hvam *et al.*, 2008]. Rather than describing each of the phases in detail, in the following, we focus our attention only on the aspects that are critical with respect to innovation and new product development (NPD).

4.1 Clarifying the innovation strategy

By implementing CS several benefits can clearly be gained [Bonev and Hvam, 2012]. Yet, when planning and performing configuration projects with complex products and multiple users, the desired results are often not being achieved. According to Haug et al. (2012) a major challenge for the success of a configuration project is that for complex products, the configuration task is difficult to be estimated. In result projects often become significantly more costly than anticipated or companies fail to create prototypes that indicate the potential benefits. Another reason for abandoning initiated configuration projects is that by implementing a CS a substantial part of the business processes have to be redesigned. In case the required organizational changes are not widely accepted by the employees, the system will most likely not be used [Haug *et al.*, 2012]. To overcome these challenges it is important to establish a clear innovation strategy that promotes configuration projects which are likely to succeed and where the risk for failure is kept to a minimum. Thus, to be able to make reasonable decisions about the right innovation strategy it is inevitable to make use of relevant performance metrics. A way of assessing the performance of NPD is through monitoring the NPD productivity measured as the output from the NPD process divided by the input [Coorper and Edgett, 2009]:

$$NPD\ Productivity = \frac{Sales\ (or\ Profit)\ from\ NPD}{R\&D\ Spending}$$

As indicated in Figure 2 below, in today's quick changing business environment the outcome of the NPD can be rather uncertain. Estimations about long term sales development of new products remain vague and can cause high risks with regard to their success on the market [Oriani and Sobrero, 2008].

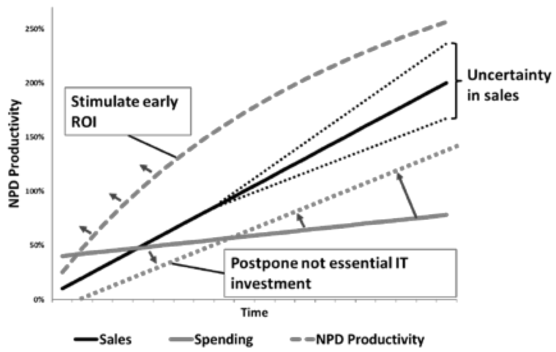

Figure 2: Effect of sales and spending on NPD productivity

In order to increase the NPD productivity and reduce risk of failure in the more reliable planning horizon, i.e. at an early stage of the innovation process, early R&D spending should be kept low. For ETO firms moving towards MC this can be achieved in two major ways. First, it is beneficial to establish strategic alliances with reliable suppliers. By sharing and coordinating innovation activities for complex products and knowledge about customer preferences and trends, individual investments and risks concerning the success on the market can be reduced [Pullen *et al.*, 2012].

Secondly, for configuration projects the R&D spending is mainly driven by the development of the configuration model and by the related IT investment. At an early stage of the configuration project it is therefore important to be clear about what are the essential ("need-to-have") functionalities the CS needs to have and which of the possible functionalities can be categorized as "nice-to-have". As the product is maturing over time and turnover from sales is increasing, further investment towards the less prioritized functionalities can be taken and the use of the CS can gradually be extended. From a financial perspective a strategic alliance and a stepwise configuration development stimulates an early return on investment (ROI) and increases the probability for more successful new product launches. Furthermore, a stepwise CS implementation encourages employees to embrace the organizational changes caused by the system, while its functionalities are being extended over time.
In sum, by involving the strategic partners in the configuration project, investment and risks can be shared and a wider range of the specification activities can be considered. Having set the requirements for the innovation strategy, in the following steps the some essential characteristics of the project life cycle will be discussed.

4.2 Developing the specification process

Before starting with a detailed analysis on the planned product innovation, if it hasn't been done yet, it is first useful to establish an overview over the current specification process at hand. From a supply chain perspective it is important to understand how the communication between various stakeholders is organized and to what extend they are influenced by the specification process. A typical sales and delivery process of ETO firms is illustrated in Figure 3 [Brunoe and Nielsen, 2012]. In contrast to mass producers, at the point of sales ETO firms usually have only a limited amount of information specifying the product and a significant amount of it has yet to be designed [Rahim and Baksh, 2003]. At the same time ETO firms still need to be able to create legally binding sales quotes which define the product to a considerable level of detail, ensuring that the communicated price and lead time results in a satisfying profit. Since generating quotations is no guarantee for receiving an order [Kingsman and De Souza, 1997], the sales process has to be effective and very cost efficient. For companies delivering ETO products the main purpose of having a CS is therefore to automate the sales and ordering process [Haug *et al.*, 2009]. In result, this initial analysis of the involved specification activities helps to assess the requirements for the subsequent automation.

Next, a TO-BE specification process supported by a CS can be defined. Scenario 2 in Figure 3 illustrates the most widespread approach for CS [Salvador *et al.*, 2009], namely a sales configurator. In other less common situations, ETO companies might have more benefits from the implementation of a solely technical CS (Scenario 2). In such a case the system would function as a design automation system for generating technical specifications for production. Due to the involvement of complex calculations, a major challenge is thereby to cover the entire technical specification [Elgh, 2008]. Next, the simultaneous implementation of both, a sales and a technical configurator is repressed by the remaining two scenarios. While in Scenario 3 two separate systems would cover the two aspects, Scenario 4 represents an integrated solution for the configuration. However, as the integration to other IT systems and to advanced calculation and CAD applications, such as to Mathcad and Inventor, is a major cost driver, in the first step this investment it is often unfeasible.

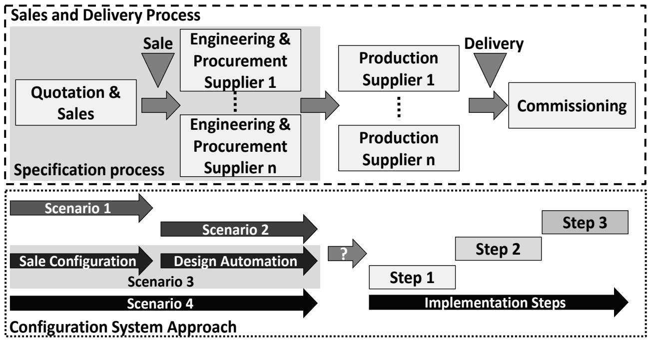

Figure 3: ETO specification and delivery process with a stepwise scenario implementation

Consequently, even though the use of advanced CS can potentially sustain the entire specification process (Scenario 4), to keep the investment costs and the organizational changes at a low level, in the first step (Step 1) of implementation, only the needed process steps are to be assisted by the system. In the subsequent steps (Step 2 etc.), more and more activities related to the specification of a product can be automated. In the majority of the cases it is feasible to start with the development of a sales CS, as for example investigated by Salvador et al. (2009). Such a system could then be used as a marketing tool, where in the introduction and growth phase of the product life cycle the focus is on creating customer awareness of the product and on trial of different product variants [Kotler *et al.*, 2012]. With the right analytical capabilities [Davenport and Harris, 2007], companies could quickly uncover customer preferences and thus further extend their product portfolio towards the required product features.

4.3 Aligning product analysis and development with configuration development

Since in most cases product innovation builds upon existing products [Smith *et al.*, 2012], after clarifying the implementation steps, an analysis of the most similar product architecture needs to be taken. Ulrich (1995) defines product architecture as: (1) the arrangement of functional elements; (2) the mapping from functional elements to physical components; and (3) the specifications of the interfaces among interacting physical components. For the analysis of the architecture, often the Quality Function Deployment (QFD) and the Design Structure Matrix (DSM) have widely been utilized. With their help customers' needs are identified and linked into the created product structure [Vezzetti *et al.*, 2011]. The employment of the Modular Function Deployment (MFD) then enables the creation on decoupled functional units, i.e. modules [Ericsson and Erixon, 1999].

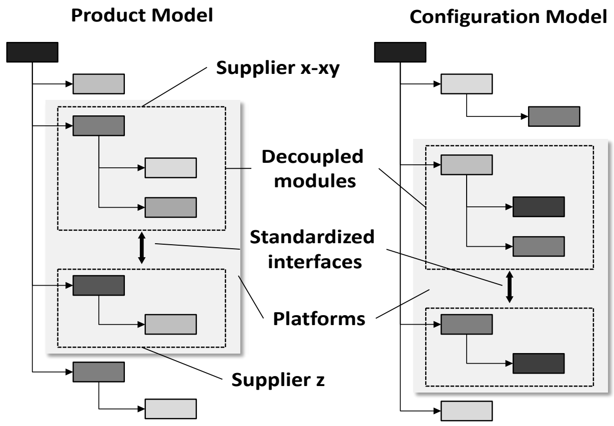

Figure 4: Aligning product model with configuration model

Another way of representing the product architecture is through the hierarchy structure of the Product Variant Master (PVM) technique. By following the basic principles of object oriented modelling, such as generalization, aggregation and association, the PVM technique uses the Unified Modeling Language (UML) standard [Hvam *et al.*, 2008]. Regardless the chosen modeling technique, with product platforms in the development process are more stable product architecture can be achieved [Meyer and Lehnerd, 1997]. To ensure the collaboration between suppliers of a complex product, the individual components should be integrated as separate modules with decoupled functionalities and with clear interfaces to the related product components. Figure 4 illustrates the integration of components coming from different vendors into the entire product model. While some of the modules may be delivered from different suppliers (indicated by “x-xy” in the figure), for other modules only one supplier (“Supplier z”) may exist.

A product model generally aims at representing the physical components and their functionalities. From an object oriented perspective, the development of a configuration model however characterizes the logical combination of classes and their attributes. Each class may represent physical components or other important product characteristics. Such characteristics could e.g. describe geographical, geometrical and functional product aspects, such as the targeted market or the shape and style of a product. Depending on the modelling environment of the CS, as indicated in Figure 4 the configuration model can then be illustrated as a PVM.

Even though the composition of the configuration model might be slightly different from the one of the product model, the same structural concerns are relevant for its knowledge base. Thus, since a growing product complexity typically leads to an increasing configuration complexity, wherever possible the configuration structure should consist of separate configuration modules (classes) with encapsulated constraints [Tiihonen *et al.*, 1996]. To simplify the model, also here standard interfaces among modules with a minimum number of cross related constraints are beneficial. Classes which can be carried over across product families are then to be grouped to platforms.

Furthermore, in cases where the final product components are unclear yet, a Concurrent Engineering like approach can be achieved by the use of a “black-box” configuration [Whitney, 1988]. In this case configuration classes which contain dummy attributes and constrains for the presumed product functionalities can be established in parallel to the development of the physical product components. Once the final components and the corresponding supplier specifications are available, the placeholders created in the CS can be fed with the actual information. Finally, by using the spiral model [Cooper and Edgett, 2008; Hvam *et al.*, 2008], a quick trial and error testing of the CS helps to detect critical configuration aspects and product components for which the product information is yet fragmented or not available.

5 Applying the Framework

The described framework for using CSs in the process of NPD of complex ETO products was tested for validation on an industrial case study. The thereby gained results will in the following be briefly discussed.

5.1 Developing the TO-BE specification process at the case company

Having established and overview of the AS-IS specification process, a TO-BE specification process for a stepwise CS implementation was created. The main requirements for Step 1 were:

1. The specification errors, long lead times and limited product representation should be improved by the use of a sales configurator.
2. The sales configurator should:
    a. Contain only product features which are essential for the customer.
    b. Store not essential product features as predefined default values and represent for the majority of the cases a well-designed product [Mandl et al. 2011].
    c. Be available locally on salesmen’s computers.
    d. Provide a sufficiently accurate (95%) price and lead (delivery) time estimation.
    e. Provide a 3D graphical user interface (GUI) of the product, where a direct impact of the configured commercial features on time and cost is to be seen.
    f. Generate a quotation for the customer including a description of the configured product.
    g. Save the customer’s information and the configuration status for a later reconfiguration.

   h. Enable the selection of non-standard choices for better adaptation of the offered solution space.
3. The remaining specification process should be divided into a configurable technical specification process and into a non-configurable engineering and procurement process.
4. The configurable technical specification process should be supported by a technical product configurator, the remaining specifications should be created in a traditional manner (through CAD and advanced calculation systems).
5. Both, the sales and the technical CS should be based on the same configuration model.
6. The output of each of the SCs should work as input for the other SC.
7. The (technical) product configurator should:
   a. Contain all design specifications of the product which can be configured within the CS.
   b. Be available on the intranet
   c. Estimate price and lead times (production, delivery, commissioning) as accurate as possible (ca. 99%).
   d. Contain only basic descriptions and static pictures of the product.
   e. Generate technical specifications and manuals for the involved suppliers.
   f. Save the configuration status for a later reconfiguration.

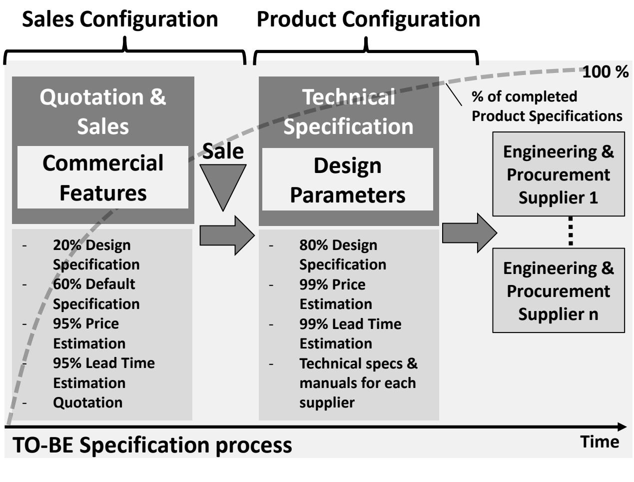

Figure 5: TO-BE Specification process of the case study

Figure 5 shows a high level representation for the chosen initial CS implementation (Step 1). To meet the requirements, a variation of Scenario 3 was selected. For the later steps of implementation (Step 2 etc.), the sales configurator should be available on the internet, where a wider range of customer awareness can be achieved. Another aspect e.g. concerns the functionalities of the technical CS. In later stages the system could have a direct integration to various CAD and calculation software, so that a higher percentage of the whole product specification can be created. However, since the product consists of components from a number of different suppliers, currently a complete definition of these 3rd party components appears to be unrealistic.

5.2 Developing the configuration model at the case company

A generic product model for yet to be developed product family was created by means of the above described modelling techniques. The corresponding configuration model was done directly in the chosen configuration software. Since both, the product and the configuration model were extended over time, the solution space of the models increased dramatically.

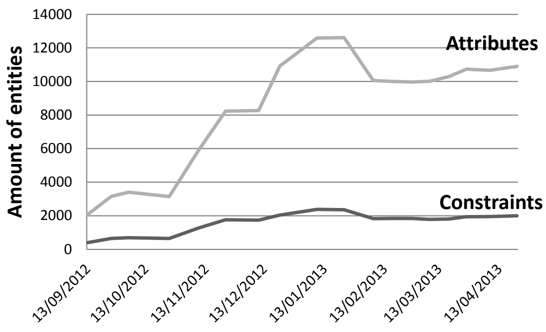

Figure 6: Progress of the configuration model

Figure 6 displays how the number of attributes and constrains of the configuration model grew as it was further completed. The growing complexity of the configuration model led to a higher computation time and to less control over the behaviour and the cause-effect relationships of the system. Hence, several initiatives were taken to reduce the structural complexity of the model. Two of them will in the following be discussed.

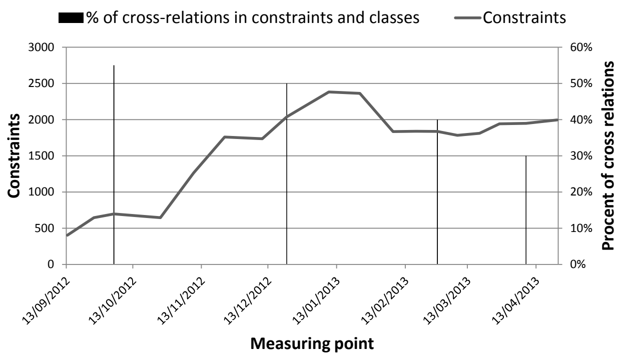

Figure 7: Reduction of cross-relations within the configuration model

To simplify the product structure, first the yet rather integrated construction of the model was redesigned to a more modular form. As described in the framework, wherever possible, it was tried utilize modularization, i.e. to make use of encapsulated classes and thus to reduce the number of cross relations. Figure 7 shows how despite a further extension of the model, a decrease from 55% to 30% cross-relations in the model considerably reduced the number of needed constraints. Moreover, having encapsulated classes with little cross-relations provided a better overview over the entire configuration model and facilitated the inevitable debugging. In cases of unexpected behaviour, computation or even system errors, the responsible classes could easier be detected.

Solution Space of 4 related attributes for Component A and B		
Category	Solution Space (No. of Combinations)	Structural Complexity
Technically possible	19,360,000,000,000	100%
Simplified each attribute by factor 10	1,936,000,000	0.01%
Simplified each attribute by factor 100 (tolerance limit)	193,600	0.000001%

Table 1: Reduction of unnecessary attribute values

Another way to reduce the complexity of the configuration structure was to minimize ranges of attributes. Since not every technically possible attribute value is required by the customer, the characteristics of each attribute could be reduced to the tolerance limit. Table 8 exemplary depicts how a simplification of 4 attributes exponentially reduces the solution space and hence the structural complexity of the knowledge base. Instead of using the technical possible solution, by limiting the ranges with factor 100 the solution space could be reduced by factor 10^8.

6 Conclusion

When following MC principles, manufacturing companies have to consider a number of characteristics. The internal and external complexity is thereby seen as a major challenge to be handled (Blecker et al., 2006). Especially for ETO companies the movement towards MC seems to be much more complex compared to mass producers (Haug et al., 2009). Their products typically comprise a low degree of standardization with no or little commonality, their processes are seldom automated and they have little control over their customer portfolio. Our study shows that in order to better cope with arising challenges, ETO firms need to pay a particular attention on the planning phase of a new product introduction and the related product configuration development. Besides the foregoing product and process analysis (Hvam et al., 2008), several additional aspects need to be considered:

1. ETO companies using product configuration should collaborate on innovation to reduce risk and investment and to become more efficient with the new product launches.
2. Configuration systems should be planned and implemented in steps by using the spiral model, starting only from the most important “need-to-have” functionalities first.
3. Configuration systems should consider the product lifecycle objectives of products, focussing first on the creation of awareness and trial of product variants.
4. Efficiency can be gained in later steps of implementation, as functionalities are being extended, and automation and further integration to other IT systems is realized.
5. The product structure of new products needs to be redesigned in order to be configurable, while 3rd party components should preferably appear as separate modules with standardized interfaces.
6. Product model and configuration model can be created simultaneously, with a focus on stable and well known components. For yet not finally designed components dummy classes with estimated functionalities can be created.
7. In order to handle the complexity of the knowledge base, the configuration model needs to follow the same objectives as the product structure, namely; (a) the use of generic and modular yet encapsulated configuration classes with little cross related constraints (standardized interfaces), (b) the implementation of standardized and decreased attribute ranges.

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