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# Complexity Management in Mass Customization SMEs

Thomas Ditlev Brunoe*, Kjeld Nielsen

*Mass Customization Research Group, Department of Manufacturing and Mechanical Engineering, Aalborg University, Aalborg, Denmark*

* Corresponding author. Tel.: +45 30541191; fax: +45 9940 7110. *E-mail address:* tdp@m-tech.aau.dk

**Abstract**

As mass customization is being widely adopted, manufacturing companies are faced with an increasing challenge of establishing and maintaining manufacturing systems with sufficient flexibility to meet customers' diverse needs and yet be efficient enough to be competitive. This is also the case in Small and Medium Sized Enterprises (SMEs), which are also experiencing a demand for increased product variety. However, increased variety in the product portfolio often implies increased complexity in manufacturing costs, which combined with low manufacturing volumes in SMEs often implies that parts of the product portfolio may prove unprofitable. This is often found to be a product management issue, where complexity increases over time, as new variety is introduced in the product portfolio, not following an explicit procedure for assessing impact of increased product variety and complexity. This paper investigates the impact of excess product variety and complexity in four different SMEs, and describes experiences with using a structured approach to assessing variety and consolidating the product portfolio. The issues found in the cases are SME specific, as the volume-variety relationship as well as the organizational resources available to perform product management in relation to new product development and adaption of the product portfolio to accommodate requirements for specific customer orders.


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*Keywords:* Mass Customization, Ramp-up Management, SME, Small and Medium Sized Enterprises, Complexity Management

## 1. Introduction

Mass Customization is a business strategy, for which the goal is to sell and manufacture goods, which are individually customized to fit individual customers' needs, while doing so at a cost level close to similar mass-produced products.. Mass Customization, introduced by Davis [1] and later operationalized and popularized by Pine [2] in the early 1990's, has since its introduction been receiving increased attention and adoption within an increasing number of different industries. Academically, Mass Customization can be defined as "producing individually customized products at a cost near mass production" [2]. Mass Customization has also grown to become a well-researched topic [3, 4], and several sub-disciplines can be identified when reviewing literature, ranging from logistics, through strategy, IT-systems and planning to organizational issues. A recent study however suggested that the capabilities, which are uniquely critical for mass customizing companies are three fundamental capabilities [5]:

- Solution space development "the ability to identify the product attributes along which customer needs diverge" [5]
- Robust process design "the ability to reuse or recombine existing organizational and value-chain resources [5]
- the ability to help customers identify or build solutions to their own needs [5]

As stated above, much research has focused on different aspects of mass customization, and a query on "mass customization" on Elsevier's research database Scopus returned over 3,000 results. However, the research on mass customization in small and medium sized enterprises has a very limited extent. A recent literature review on mass customization in SMEs identified less than 40 publications


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available through Scopus and Thomson Reuters Web of Science [6]. According to Eurostat, in the European Union 22.3 million SMEs were operating in the non-financial business. These SMEs contributed with 57.5% of the value added in this sector in EU, and employed 67% of the workforce. Furthermore, it is commonly acknowledged, that the challenges in operating an SME are significantly different from those experienced in large enterprises. As Welsh expressed it already in 1981: "A small business is not a little big business" [7]. Given that SMEs are vital to the European economy, and the fact that very little research has invested in mass customization research, it seems there is a research gap that needs to be addressed. One challenge, which can be found in both SMEs and large enterprises, is the challenge of increasing product variety .

Various research has concluded that excess complexity in a company's product portfolio has a negative influence on Operative performance. An empirical study by Adani et al. reported that best practice companies in reducing complexity in terms of component standardization and number of suppliers were able to perform significantly better on several operative performance parameter such as running capital cost, obsolescence cost, transportation cost and administrative cost, compared to the average of that particular industry [8].

When companies engage in mass customization, it is inevitable that product variety increases, and there is hence a risk of a reduction in operational performance. On the other hand, the competitive environment in Europe, especially parts of Europe with high wages, such as Denmark, pursuing a mass customization strategy is often a necessary business strategy, since the production of standard products is often performed in low wage countries in the Far East. Hence, these companies must find a way to balance product variety with standardization and efficiency. It has long been acknowledged that modularization and product platforms are effective ways of addressing the tradeoff between variety and commonality [9, 10], however, many SMEs still find challenges in operationalizing these principles.

Complexity management is a term, which refers to how companies can handle increased product variety, and thereby complexity in product portfolios, and complexity in business processes and manufacturing. The focus of this paper is centered on the combination of complexity management and SME. The research question of this paper is:

*What are the major challenges SMEs experience in relation to complexity management and how can these challenges be addressed?*

In this paper we delimit the study to the part of complexity management which related to controlling and reducing product variety, since reductions in product variety will usually lead to reductions in other types of complexity, such as process complexity, supply chain complexity etc.

## 2. Methods

Since very literature exists on complexity management in SMEs we have chosen to address the research question using a multi case study as this allows us to explore a wide range of different companies in different businesses and with different challenges. Five different companies are included in this study. The included companies are all SMEs which are manufacturing customized durable goods. The companies were studied during the course of a research and knowledge dissemination project focusing on mass customizing SMEs. The aim of the project was to disseminate state of the art knowledge on mass customization and related methods to Danish SMEs manufacturing customized products. The five SMEs are described briefly below and referred to as case A through E:

**Case A** is a company manufacturing customized and high-end luxury building components. This company has in the range of 20-49 employees. Products are manufactured in various wooden materials with smaller metal components. Product variety is on materials, dimensions and combinations of different additional components.

**Case B** is also manufactures customized building components, however mid-range high quality products. This case has in the range 50-99 employees. Products are manufactured in various wooden materials with smaller metal components. Product variety is on materials, dimensions and combinations of different additional components.

**Case C** manufactures heavy contractor equipment and employs around 200 people. Products are assembled from a high number of primarily metal components which are a combination of own production components and components from sub-suppliers.

**Case D** Also manufactures contractor equipment but employs only in the range of 20-49 people. Products are assembled from a high number of primarily metal components, which are sourced from sub-suppliers.

**Case E** manufactures small components for process equipment and employs in the range of 20-49 people. Products contain a few components and are assembled mainly from metal components of own production and a small number of purchased standard components.

Throughout the project, a number of workshops were conducted where companies were asked to map their product variety and asses this product variety in relation to customer demand for variety. This was done using the method described by Mortensen et al. [11] called product variant master, where three views; customer, engineering and production view are modelled using two mechanisms; the "part of" and the "kind of" mechanisms. The "part of" mechanism corresponds to BOM like product breakdown, and "kind of" corresponds to branching, where different modules can be used in the "part of" structure.

Together with each company, areas were selected for further analysis and transfer of knowledge on methods to improve the company. In the results section below, the challenges experienced by each company will be described, as well as potential solutions identified through the project as well as an analysis of why these challenges are considered SME related.

## 3. Results

### 3.1. Case A

This company had not explicitly described any formal product families, and had thus not any formal descriptions of predefined or allowed product variety. This implied that when quoting customers for new products, the sales person would either need to start from scratch specifying the product or find a similar product previously sold and alter this quotation to fit the customers need. A few key employees held a great amount of tacit knowledge on which products would work in practice and which products would be possible to manufacture. This implied that sales and order processing was very dependent on a few key employees. The company has a growth strategy, and even though the production facilities could easily accommodate larger production volumes, the sales and order processing are currently the bottleneck, as they depend on the tacit knowledge of a few people.

After discussing possible solutions with the company, it became apparent that the obvious solution would be to formalize the product families by establishing product family models, clearly stating what product variants can be sold and manufactured and which cannot. Based on this a product configurator will be developed, which will allow any sales person or even customers to configure products conforming to the product family model, thus ensuring that only valid configurations are made.

The challenges identified in this case are believed to be SME related, since the main reason to the product and production knowledge not being formalized is due to the company being very small, and there has not previously been any pressing need for sharing knowledge. Furthermore, the limited resources, people and money, have been somewhat limiting in relation to developing and implementing a product configurator since this is quite often a rather expensive software.

### 3.2. Case B

This company has challenges, which are similar to case A, however this company has to some extent formalized the description of their product families. In this case a rather high number of product families have been defined, and in some cases, the company was not able to justify why two very similar product families were defined, since they provided little or any differentiation towards the customer. This could indicate a potential in “cleaning up” the product portfolio and merging existing product families, which are redundant. This would be beneficial for the company, since having too many product families implies more administration and less economy of scale. Furthermore, the company had paid little consideration to part commonality between the product families, which according to the company could contain a big potential for reducing the number of different parts and manufacturing processes necessary for manufacturing the different products in the product portfolio. Finally, this company had a manually based price calculation in Excel sheets, which has shown to be difficult to keep up to date with current prices.

It appears that a solution to address the challenges in this company would also be to initiate a process, where product family models are created so that it can be identified where different product families can be merged, and where different product families can be slightly modified to obtain a higher degree of cross product family component commonality. Furthermore a product configurator would reduce the maintenance and manual processes related to the current manual price calculations.

The reasons why the challenges in this case are SME relevant are similar to those of case A, i.e. a high degree of tacit knowledge due to a small staff and limited resources to run improvement projects.

### 3.3. Case C

This company is very different from the two presented above, since the products are much more complex, much more expensive and sold in much lower volumes.

Contrary to the two cases above, this company has a product configurator, which is implemented in Microsoft Excel, which allows sales people to easily quote customers within the allowed product variety. This configurator was created by “coincidence” since one employee in the service department had a personal interest in the project and did it on his own initiative. The main challenge identified in this company was somewhat similar to one challenge described for case B, that the company has very little commonality across the different product families, despite the fact that they are quite similar and share the same functions. This implies that where identical solutions, components and production processes could have been reused, they are in fact different. In case B this was a problem due to administration and purchasing volumes, but in this case, since the products are much more complex and in much lower volume, it becomes a problem in relation to product development and product management, as a quite large part of the company is engaged with product development. Sharing more modules across product families would potentially free resources from the product development and engineering department to increase the performance of the modules even more or to faster introduce more new products.

A potential solution for case C would be to restructure the approach to product development, to focus more on developing module platforms, which can be developed to fit within multiple product families. Prior to doing this, the company must also perform an analysis of the functional breakdown of the product families to identify shared functionality. A process, which has already been initiated in the company.

The challenges experienced in this company are clearly also to the fact that they are an SME, since the sheer size of the company typically implies that they focus more on short term goals or developing “one product at a time” instead of following a structured platform approach.

### 3.4. Case D

Although still an SME, this company is by far the largest in this study. This is likely the reason why this company is farther along with the process of modularizing and standardizing their

modules across their different product families. Using a radically new approach (to this company), the company has undergone a process where module commonality has become a part of the basic approach to product development. Modularization and standardization are thus not topics, which indicate the same potential as in the other cases, since this company has already realized these potentials. The company also has a well-functioning product configurator, allowing sales people to configure any product within the product families, and again contrary to the other cases, this is no significant improvement potential.

What this company experiences as the largest challenge in relation to variety is actually the consequences of large product variety in the production system. The company manufactures almost all of their main steel components themselves, and because they are contractor equipment, these components are quite large. This implies that large fixtures are needed to manufacture these components, and since the company has several product families each with a high number of components, the number of fixtures is high and the space they take up is quite large. Furthermore, setting up the fixtures is very time consuming, which in turn would encourage the company to produce in larger batches. However, manufacturing in larger batches would imply very large stock due to high product variety and low volume. Hence, the company faces a difficult tradeoff between stock level and manufacturing efficiency.

The solution, which has been identified to address this is reconfigurable fixtures, where families of components with similar size and geometry are identified, so that flexible fixtures can be designed for future products, significantly reducing the number of different fixtures and the time needed for changing over, given that similar components are manufactured one after another in smaller series. Preliminary work on designing these fixtures show promising results.

The main reason why this an issue in this particular company is that the company sells small volumes compared to its competitors. Smaller volumes mean that manufacturing in larger batches is unprofitable due to stock levels.

### *3.5. Case E*

The products of Case E are significantly smaller and less complex than those of case C and case D, and are sold as system components in process plants. The products apply a modular product architecture, both in terms of the products' internal structure, but also in terms of the products' interfaces to the systems with which they are integrated. The latter is due to established industry standards, whereas the first is due to the approach to product design.

The company's approach to manufacturing and selling products has traditionally followed a make to stock approach with a high number of product variants, which are listed in catalogues and kept in stock.

Since the company is fairly small and their sales volume on this range of products is also relatively low, the volume per product variant is very low. Since the company follows a make to stock strategy, and they want a high service level, the high number of variants implies that they need a large stock, which is expensive. Since the company recognizes that high stock levels is expensive, they attempt to limit the stock levels, which then influences the actual service level towards customers. Given the relationship between the low demand and very high variety, it seems that the catalogue approach and make to stock strategy is a challenge for the company. Adding to this, the company frequently get requests for "non-standard" products, where e.g. a single component is replaced by a component complying to a specific customer request, without changing the structure of the product or any other components. In the current setup, this is a challenge since this these requests are handled ad hoc with risk of errors and a sprawl of new item numbers and bills of materials are some of the negative results.

After discussing with the company, it appeared that a potential solution addressing the issues above would be changing the approach to sell and manufacture products entirely. Moving from predefined items and predefined BOMs towards selling configured products, where BOMs are auto generated for each configuration, and products are assembled to order instead of manufactured to stock would to some extent address these issues. This would move the customer order decoupling point to a later point in the value chain and likely reduce the stock levels, as a lower number of components / modules would be necessary to produce the demanded finished products. Furthermore, configuring products would increase the flexibility to introduce new variants by adding single components, thus introducing a more structured yet flexible approach to handle special customer requests.

The challenges identified in this case are SME related in much the same way as in the other cases. The relatively low volume is typical for SMEs, where larger companies would likely have higher volumes per variant, making a make to stock strategy less of a problem.

### *3.6. General Observations*

In relation to the project described in section 2, for each company a process was performed, where a simple model was made of the product families in the company's product portfolio. This was done using the product variant master method described by Mortensen et al. [11]. This approach provides an intuitive approach to mapping product families' physical architecture and compare it to the actual customer demand for product variety, to identify excess variety and potential for increased commonality. The most important outcome of his process was not so much the final result, as it was the discussions that were sparked by mapping the product variety, which helped to identify improvement potentials and low hanging fruits during the process.

In every company, the participants were able to identify excess variety, which could seemingly be removed from the product portfolio without reducing variety in function or features as perceived by the customer. This indicates that the SMEs included in this study can gain significant benefits from improving complexity management, as they would be able to increase economies of scale, if variety and thus complexity were reduced.

Many of the companies had in some form or another introduced product configuration, however, no one company

had introduced a large scale configurator solution using dedicated configurator software. One reason for this could be the relatively high investment related to purchasing and implementing a configuration system. On the other hand, the companies did gain some benefit from other simple solutions such as spreadsheet configurators.

Table 1. Summary of results

| Case | Challenges | Solutions |
|---|---|---|
| A | - Tacit product knowledge<br>- Bottleneck sales process<br>- Missing predefined variety | - Formalize / establish product family models<br>- Develop product configurator |
| B | - Excess number of product families<br>- Little cross-product family commonality / reuse<br>- Manual price calculation | - Product family consolidation<br>- Module standardization<br>- Develop product configurator |
| C | - Little cross-product family commonality / reuse<br>- Large resource investment in individual product development | - Functional breakdown of product families to identify common functions<br>- Shift towards platform development |
| D | - Product variety imposes variety on production equipment variety<br>- Process equipment variety imposes long changeovers and low efficiency | - Reconfigurable tooling to reduce equipment variety and changeovers |
| E | - High number of predefined variants and low volume per variant<br>- High inventories and low service level due to high variety and MTS production<br>- Difficult handling of non-standard requests | - Shift towards configured products and auto-generate BOMs, based on existing modules<br>- Shift production from MTS towards ATO. |

## 4. Conclusions

Through case studies of five different SMEs, which were all manufacturing customized products, it was found that every case company had mass customization specific challenges, which could be related to the fact that they are SMEs. The more specific reason were in all cases related to either low sales volumes or limited organizational resources, something that is relevant in many SMEs. The results are summarized in table 1. below.

Relating the challenges and identified solutions to these challenges to the three fundamental mass customization capabilities, solution space development, choice navigation and robust process design, described above, it is seen that the challenges and solutions were found in every capability. This relation is shown in figure 1. In two cases, the challenges and solutions were isolated to just one capability and in one case, the company faced challenges in every capability, which could however be addressed by improving two capabilities.

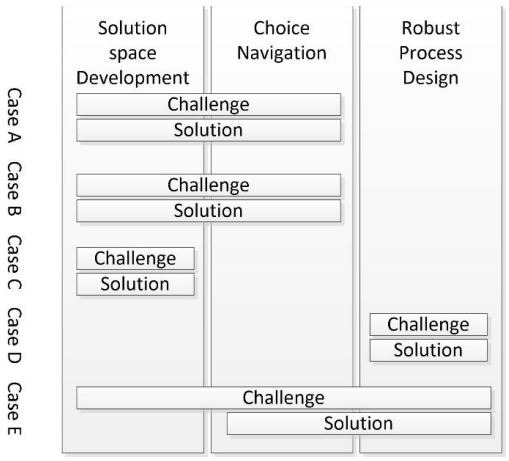


Figure 1. Relation between challenges and solutions, and the three MC capabilities

One main conclusion which can be drawn from this study is that complexity in products and production can be great challenges for SMEs. Furthermore, out of the literature published on complexity management, and mass customization in general, very little is targeted SMEs. However, as we have shown in this study, SME specific challenges exist, which calls for future research focusing on complexity management in SMEs specifically.

By focusing future research on the SME specific challenges which relate to managing complexity in a product portfolio, there is a large potential in helping SMEs towards becoming much more efficient in product development, product introduction, ramp up and operation. However, this requires academia to further identify the specific challenges, and to develop methods which can easily be applied in the specific context of SMEs, where the volume-variety relationship is much different from large enterprises, and scarce resources are typically available for running projects such as variety reduction as focus tends to be on the day to day operations.

A company's ability to perform fast and efficient ramp up may be greatly influenced by the company's complexity in products and production system. Since SMEs will typically have scarce resources to perform the ramp up process, handling complexity becomes even more important. One reason why this is important is that if a company can limit its internal product variety, i.e. reuse existing components or modules in future products, fewer new modules or components must be introduced in the production system, when new products are ramped up. Hence, managing complexity is one key to achieve an efficient ramp up process, particularly in SMEs.

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