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SOLUTION SPACE ASSESSMENT FOR MASS CUSTOMIZATION

Thomas Ditlev Brunoe, Kjeld Nielsen, Kaj A. Joergensen
Aalborg University, Department of Mechanical and Manufacturing Engineering, Aalborg, Denmark

Abstract: *In mass customization, the capability solution space development is essential to offer a variety of products which satisfies the idiosyncratic needs of the customers. We argue that there is a need for methods which can assess a company's solution space and their capability to develop it. Through literature study and analysis of solution space characteristics a number of metrics are described which can be used for solution space assessment. They are divided into five caterories: Profitability, Utilization, Variety Demand satisfaction, Architecture and Responsiveness. The metrics and be applied as KPI's to help MC companies prioritize efforts in business improvement.*
Key Words: ***Mass Customization, solution space development***

1. INTRODUCTION

In any company it is essential to offer products which match the needs and desires of customers to achieve sales and profit. This is true for mass producers as well as mass customizers; however in mass customization this issue is somewhat more complex than mass production due to a much higher variety and a more complex product structure. As pointed out by Salvador et al., mass customizers need three fundamental capabilities to be successful: 1) Solution Space Development – Identifying the attributes along which customer needs diverge, 2) Robust Process Design – Reusing or recombining existing organizational and value chain resources to fulfill a stream of differentiated customer needs and 3) Choice Navigation – Supporting customers in identifying their own solutions while minimizing complexity and the burden of choice [11,17].

In order for companies to be able to establish themselves as mass customizers or for existing mass customizer to improve performance, it is proposed that a set of methods for assessing the three capabilities is developed. In this paper, the focus is solely on the capabilities for solution space development. The research question for this paper is: What parameters can be used to assess capabilities for solution space development and how can these be determined?

The solution space is a definition of which combinations of configuration variables are offered to customers corresponding to features, options or module selection. According to Salvador et al. solution space development is a matter of identifying the idiosyncratic needs of the customers and delineate what products will be offered and which will not, or put in other words, which customer needs to meet and which not to meet [17]. The goal of solution space development should be to develop an optimal solution space. However optimality can be with respect to a number of different criteria, e.g. maximum accumulated profits, satisfying the most customers' demands or minimizing the variety. It is thus not trivial to determine what the optimal solution space is.

2. SOLUTION SPACE DEVELOPMENT

Salvador et al. presented a number of approaches to develop these capabilities, which were 1) innovation toolkits, 2) virtual concept testing and 3) Customer experience intelligence [17]. However, these approaches are methods for developing the solution space rather than assessing the solution space.

Two different perspectives are relevant when assessing a company's solution space development capabilities. The first perspective is concerned with assessing the capabilities for conducting the process of defining the solution space, i.e. a process view. The second perspective is concerned with how well the solution space serves its purpose, i.e. an analysis of the result of the solution space development. The two perspectives are closely linked, meaning that if a company has a good capability of developing the solution space, they are very likely to have an appropriate solution space. In the following, we assume that a company's capability to perform solution space development can be assessed by assessing the result of this process, i.e. the solution space.

2.1 Marginal view

To describe the mechanisms of solution space development, we take a marginal view, i.e. describe what happens when new variety is introduced into a solution space by e.g. offering a new option which customer can choose. Ideally introducing new option will lead to products being sold including this option thus increasing turnover by either increasing the number of products sold or by being able to charge a higher price for those products sold including that new option. However all new options cannot be equally successful and some will inevitably lead to greater increase in sales than others.

On the other hand, introducing a new option comes at a cost. This cost may include product development, implementation in product configurator and other IT systems, tool preparation and additional manufacturing cost. Obviously, for the introduction of the new option to be successful the increase in turnover should at least exceed the total costs of the introduction.

Unfortunately, it may not be trivial to calculate the true profitability of the introduction of a new option due to a number of factors. First, it is quite difficult to calculate or even estimate the actual cost of introducing a new option, especially on beforehand if using it as a decision tool. Secondly, it is obviously also difficult to predict the sales of a new option, not only because of the difficulties of forecasting the sales volume, but also because introducing a new option may cannibalize other options, which are then rendered less profitable. This could be the case if an option is introduced which is practically indistinguishable from an already existing option. This could lead to figures indicating that the new option is seemingly profitable but at the expense of other options potentially leading to sub optimization of the solution space.

2.2 Solution space sets

In order to establish metrics for solution space development and developing measurement techniques, it is important to have some sort of idea of what constitutes a "good" solution space or even an optimal solution space.

The optimality of a solution space can be described by defining two sets of products: 1) the different products offered by an MC company, defined as the set SS (Solution Space) and 2) the variety of products which are demanded by the customers, defined as the set CDV (Customer demanded variety). As illustrated in figure 1, the intersection of the two sets will represent the products offered by the MC company which correspond to products demanded by customers. The intersection of the two sets thus represents the products that customers may buy, given they are able to find and configure the products and willing to pay the required sales price.

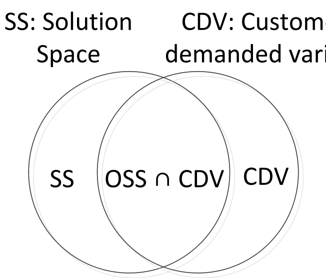

Fig. 1. *The intersection of offered variety and customer demanded variety yields the potential sellable products.*

Intuitively, maximizing the set SS∩CDV would seem like a good idea since this would maximize the potential number of product variants that can be sold to customers. However, one must bear in mind that all variety comes at a cost and attempting to satisfy each and every customers demand for variety can lead to soaring costs in relation to product development, manufacturing cost and sales costs.

It would also seem intuitive that the set SS \ CDV i.e. products which are part of the offered variety but are not demanded by customers should be minimized or even eliminated. This is partly true since these products are per definition not sold and will thus not contribute to turnover. However these variants may be combinations of other variables which are demanded by customers and do thus not induce additional cost, implying that removing this variety would potentially be more expensive than keeping it.

When describing the solution space as set, it should be defined which elements are in the set. As presented above, each element in the sets will correspond to a unique product variant. Following this, each possible combination of configuration choices would correspond to a variant and thus an element in the set. However, for most MC product families, the number of elements becomes astronomical due to numerous configuration variables each with a number of outcomes. For example, when configuring a Mini Cooper online the configuration choices presented to the customer will result in a number of possible variants well above a 20 digit figure. This is obviously significantly more than the potential market of the Mini Cooper. Assuming that the sale of Mini Coopers is a good representation of the demanded variety, and the Mini Cooper has sold a few million cars and assuming that each sold Mini Cooper is unique, the customer demanded variety will only be a tiny fraction of the offered variety and as a consequence. Furthermore we would expect that assessing whether single variants would counter a demand from a customer is simply not possible if the number of variants is high. Thus it would seem that variants defined as all possible combinations of configuration variables is not an appropriate way to define the solution space set as well as assessing the intersection of SS and CDV.

2.3 Solution space representation

A more simple and comprehensible way of representing the sets may be defining the elements of the sets as the "dimensions of customization". If a product has a number of customizable attributes and each attribute has a finite number of values that can be chosen, each value will correspond to a product property which can potentially be demanded by a customer. Figure 2 illustrates the definition of solution space set and customer demanded variety set, using a fictive example of a customizable shirt, where three different colors, four different sizes and two different sleeve lengths can be customized. Each element in the set SS corresponds to one value of a customizable attribute, e.g. the attribute "Color" having the value "Blue". In this example the color red is contained in the solution space set but not in the customer demanded variety and is thus unnecessary variety increasing costs without increasing sales. The element representing the attribute "Size" with value "x-small" is contained only in the set CDV and is thus not offered by the current solution space. This implies that there is an unfulfilled customer demand which could be satisfied by extending the solution space thus increasing the customer base. Obviously the elements in the intersection of the two sets represents customer demanded attribute values which are fulfilled by the current solution space, and no action is seemingly required.

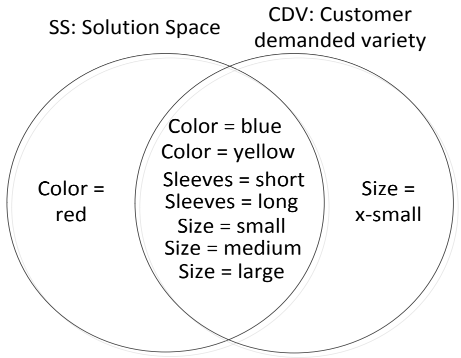

Fig. 2. *Example of definition of solution space set based on attribute values*

If the example presented in figure 2 were reconstructed defining each element as a unique combination of customizable attributes, the set SS would contain 18 elements instead of 8. If an extra customizable attribute were added with two possible values, this figure doubles. Generally the size of the set will increase exponentially when adding customizable. Using the approach illustrated in figure 2 the sets grow linearly when customizable attributes are added. Returning to the example of the Mini Cooper, representing the solution space by possible attribute values would lead to a set of less than 100 elements rather than the 20 digit number of possible combinations.

We thus propose that the solution space is described by the number of customizable attribute's values. Defining the solution space this way is trivial, since an MC company's offerings will usually be explicit in a configurator, product family model or other documentation. Defining the set CDV on the other hand is far more difficult since it will be impossible or at least extremely time consuming to clarify all potential customers' demand for variety. Also this would depend on the delimitation of the product family's intended customer base. As a result, measuring the size of CDV will expectedly be practically impossible.

As mentioned previously, whether an attribute value is in the intersection of the two sets or only in one of them would indicate an action, however this is not necessarily true. The reason for this is the fact that all customizable attribute values are not likely to be subject to the same demand. Hence some attribute values will be sold very frequently while some are perhaps rarely sold. In the case where an attribute value is rarely sold, addressing the solution space as a simple set would conclude that the attribute value is demanded by customers and should thus be included in the solution space. However due to lack of volume the cost of producing the product corresponding to that specific attribute value may exceed the sales price of the product.

This indicates that viewing the solution space and customer demanded variety alone is not sufficient to assess the optimality of a solution space. This must be supplemented with a measure of e.g. how frequently a certain attribute value is demanded and preferably whether offering that specific attribute value is profitable. For the elements present in the intersection of SS and CDV this could be possible since historic data is present to analyze. However, for elements not previously part of the solution space but are considered by a company to include in the solution space due to recognition of a demand for variety, this assessment is more challenging. This is due to the fact that the assessment must be based on predictions of the future which are inherently uncertain. On the other hand, if this assessment could be performed, it would enable mass customizers to make qualified decisions regarding the development of their solution space.

2.4 Requirements for solution space assessment.

Concluding on the considerations above, we propose that it would be beneficial for mass customizers if an assessment of the solution space could be performed. This assessment should be able to measure the "utilization" or "efficiency" of the solution space as well as the profitability.

However, assessing the utilization of profitability of a certain solution space provides only a snapshot of the current state of a company's offerings. Recognizing that today's markets are ever more rapidly changing, it is relevant also to evaluate the responsiveness of a company related to the solution space development, i.e. how fast and efficient is a company able to change its solution space according to new market demand. This could either be a new customer demand for variety that needs to be recognized, developed and offered through the sales channels as fast as possible. On the other hand, it could be the disappearance of a customer demand for variety caused by internal or external factor. This could be legislation, competitor offerings or new products within the company's own product portfolio which significantly reduces or completely removes the demand for a particular attribute value ultimately rendering it unprofitable to offer that option. This attribute should naturally be removed as fast as possible to avoid economic loss and the pace at which this happens indicates a different form of responsiveness. One other factor relevant to assessing the dynamics of solution space development is the cost of developing the solution space, i.e. how much does it cost to introduce a new attribute value.

Hence, in order to assess a mass customizer's capability it will also be relevant to address these different types of responsiveness apart from the current state of the solution space.

In the following section the literature within mass customization has been reviewed to identify possible methods for solution space assessment.

3. LITERATURE REVIEW

Desmeules analyzed the relationship between the variety perceived by the customer and the customer happiness [4]. Of course increased variety provides increased customer happiness to some extent, however due to a number of factors, once the variety reaches a certain level, the increase in customer happiness levels out and eventually drops. In figure 3, this relationship is illustrated as an inverted U shape. The mechanisms that create the upward slope, thereby increasing customer happiness are well known and proven in MC literature. The point where increased variety levels starts reducing customer happiness is however very interesting for companies, since this would indicate some sort of variety optimum for a solution space. The reasons for the downwards slope are that the number of choices become overwhelming and the customers ability to self regulate the process fails resulting in frustration and indeed reduced customer happiness.

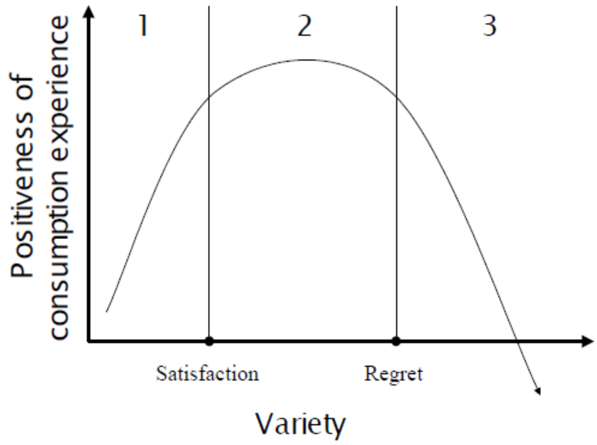

Fig 3. *Relationship between perceived variety and positiveness of consumption experiences* [4].

Desmeules suggests that increased customer knowledge about product characteristics would cause the point where customer happiness drops to shift to the right, which seems reasonable. This implies that better information during the sales process would allow utilizing a higher product variety.

Rathnow [16] also proposed that the benefits of increasing variety seizes at some point, although he does not suggest an actual drop in customer benefits. However the costs increase exponentially as the variety is increased. This is illustrated in figure 4, where it is suggested that the difference between cost and benefits, both functions of the variety, defines the benefit overplus. The optimum variety is defined as the degree of variety where there is the greatest difference between cost and benefit referred to as the maximum benefit overplus. However, this is only conceptually described and is thus difficult to apply in practice unless the benefit as a function of variety can be quantified.

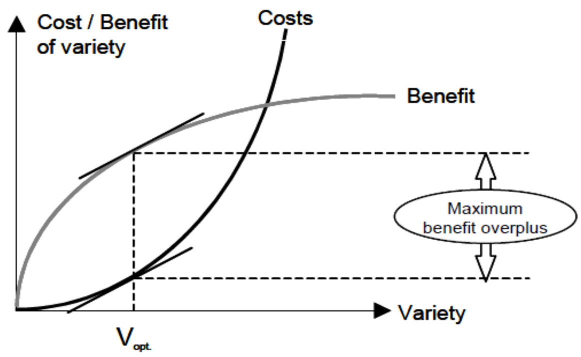

Fig. 4. *Description of the optimum problem of variety. Original source* [16], *reproduced from* [2]

Hichert [8] (referred from [2]), defined the effects on manufacturing cost from increasing product variety. He described that increased variety brings along higher unit costs due to increased manufacturing complexity, however some of these increases in cost are not reversible by reducing variety. This is due to investments in e.g. building, IT systems, machines etc, which cannot simply be sold off without a loss if the variety is reduced and the manufacturing complexity is sought reduced. This leads to a cost remanence, which is the difference between manufacturing costs prior to and after an increase and decrease in variety as illustrated in figure 5.

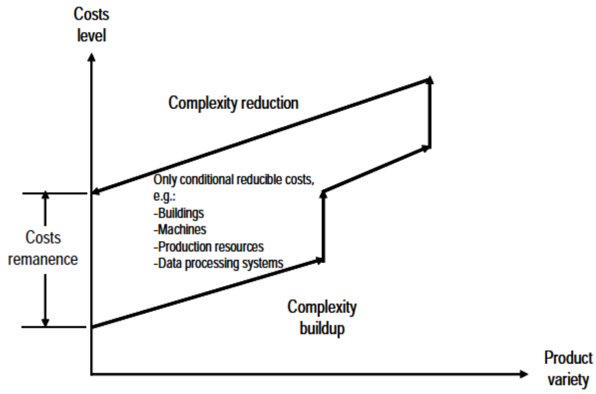

Fig 5 *Costs remanence by reducing variety* [8], *Reproduced from* [2].

This emphasizes the need for solution space development capabilities in mass customization, since wrong decisions about increasing variety may lead to irreversible negative consequences.

Piller et al. developed a model of the economy of mass customization and customer integration [15]. Increased variety will increase the customer willingness to pay price premium for a customized product. However increased variety usually implies increased costs in relation to manufacturing but also transaction costs due to a more intensive customer interaction in the sales phase. The increased costs can according to Piller et al. be countered by the principles of MC e.g. modular products, flexible manufacturing, IT system etc. However apart from this, the term “Economies of Customer Integration” is introduced, which are additional mechanisms which can counter increased costs. These include: 1) postponing some activities until an order is placed, 2) more precise information about market demands and 3) The ability to increase loyalty by directly interacting with each customer. When developing a solution space it is thereby relevant not only to balance sales volume with manufacturing costs but also take the mechanisms of “Economies of Customer Integration” into account.

Gu et al. presented an optimization method for MC products which seeks to maximize the manufacturing efficiency [7]. This model suggests increasing the commonality on different BOM levels and thereby maximizing the number of “mass production steps” and minimizing the customization steps during the manufacturing process. While this model would help in improving manufacturing efficiency given a certain set

of functional requirements, it does not address balancing the customer demand for customization with the manufacturing efficiency.
Kumar formulated a number of metrics for customization, mass production and modularity, thereby measuring the number of modules, combinations and theoretical production volume per module. The main metrics were: 1) average number of options per feature, 2) Maximum number of configurations 3) average number of configurations per customer 4) Degree of customization and 5) average demand per option per period [10]. These metrics are useful in relation to describing the variety of a product family, however less useful in relation to assessing whether some options are configured less frequently than others potentially rendering them less profitable. Furthermore, these methods do not enable assessment of whether the variety offered is actually the variety demanded by customers.

Syam and Kumar [18] analyzed the relationship between standard goods, customized goods and competing products to clarify the effects of offering customized products. They concluded that it may be beneficial for a company to offer a mix of standard and customized products, to satisfy different segments. This point is essential in relation to solution space development, since standard products can be offered to special segments to achieve overall optimality of the solution space. The paper however uses synthetic models to evaluate their hypotheses and provides thus no practical guidelines for assessing the solution space consisting of customized and standard products and do also not provide general guidelines for defining which products should be sold as standard and which should be sold as customized products.

Several authors approach the design problem in developing MC products effectively by quantifying customer value and estimating product cost [9], [12],[6]. However, none of these are found to provide metrics which are useful for assessing an existing solution space.

Gu et al. [7] present an optimization method for mass customization, primarily through standardization, but does not take into account the relationship between customer demand and the offered variety.

Blecker et al. [1] presented an extensive system of metrics for variety steering which is probably the most usefull work in relation to identifying metrics for solution space development. Based on a sub-process model representing the essential sub-processes of mass customization a number of metrics are identified to form a system able to assist in making decisions regarding variety. Hence the work aims at providing a tool for solution space decisions rather than providing an assessment, however several elements can be adopted to that purpose. The identified metrics are related to four different "zones": 1) customizable attributes, 2) product architecture and configuration system, 3) variety driven internal complexity and 4) customers and sales. The specific metrics that are considered relevant for assessing the solution space are:

- Platform efficiency metric [13]
- Multiple use metric [5]
- Interface complexity metric [5]
- Used variety [14]
- Modules commonality metric
- Parts commonality
- Percentage of standardized parts
- Number of new introduced customizable attributes during period ΔT
- Number of eliminated customizable attributes during period ΔT
- Customer churn rate at ΔT
- Growth rate
- Repurchase rate
- Sales
- Configuration abortion rate

Each of these metrics are linked closely to the solution space and will be affected when changing the solution space. Some of the metrics are indeed influenced by the solution space but not exclusively, meaning that they are influenced by other factors. One example is sales, which would be influenced by seasonality, market trends, marketing effort etc.

3.1 Conclusions from literature

From the literature above, it can be concluded that several authors have developed different ways to describe the solution space in Mass Customization. Some have addressed this conceptually, which points out specific areas to measure. However, few have addressed the issue of assessing the performance of a solution space and the capability to develop it.

We have not been able to identify any literature which has described practical guidelines for assessing a solution space as well as examples of implementation are absent. However, a few publications provide metrics which seem to be applicable for assessing a solution space. These are in particular those presented by Blecker et al. [1] and Kumar[10]. However, compared to the issues presented in section 2.4, additional metrics will need to be developed. In the following section, a list of relevant metrics from literature and new metrics will be presented.

4. METRICS FOR SOLUTION SPACE ASSESSMENT

The metrics for assessing a company's solution space as well as their solution space development capabilities need to reflect the requirements described above. Furthermore metrics need to be measurable; otherwise they are per definition not metrics. This means that for each metric, the required data should preferably be readily available in the company or should be easily obtainable. Luckily, most MC companies have information systems which could support this, such as configurators, Product Lifecycle Management (PLM) systems, Enterprise Resource (ERP) systems, Engineering Change Management (ECM) systems etc., which we expect would provide most of the required data.

The metrics are divided in five categories depending on what they are intended to measure. These categories are shown in figure 6 and described in the following along with the specific metrics.

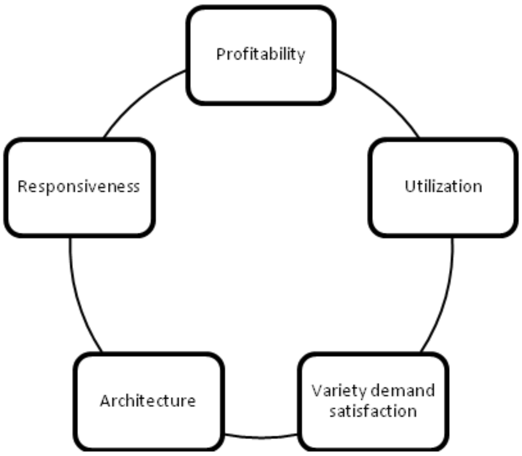

Fig. 6. *The five categories introduces to measure Solution Space.*

4.1 Profitability

Within this category, the authors have identified no metrics in the literature. What this category of metrics is supposed to measure is how profitable the mass customized products are. The reason this should be measured is the assumption that the capability for solution space development is a prerequisite for being a successful mass customizer, i.e. profitable mass customizer. Hence, a profitable product portfolio will indicate a well developed solution space. The following metrics are defined:

Aggregate solution space profitability **(ASSP)** is a measure of how profitable the solution space is as a whole and should be measured over a period of time:

$$ASSP = \text{Total Sales income} - \text{Total manufacturing cost} \quad (1)$$

We propose to also introduce a metric measuring profitability per product family **(PFP)**, calculated similarly over a period of time. This however sets additional requirements do data availability, as manufacturing costs must be registered more detailed:

$$PFP = \text{Sales income from product family} - \text{manufacturing cost for product family} \quad (2)$$

We also propose a metric for Configuration Variable Profitability **(CVP)**, which is somewhat less trivial to determine. However if historical configuration data is available with sales price and manufacturing costs registered for each configuration it is possible to generate a linear model describing the variation in price and cost from the configuration variables using the methods described by Brunoe & Nielsen [3]. From the significance and coefficients for each variable, it will be indicated if a specific configuration choice is profitable, e.g. a specific color. However assessing each variable may be useful in solution space development choices but less useful in assessing a company's overall capability, since it will consist typically of hundreds of figures, corresponding to the number of configuration options. However, once the profitability for each option is calculated, the distribution of profitabilities may be analyzed. What is interesting here is how many configuration variables (percentage) have negative profitability **(NPCV)**. Obviously, this figure should be as low as possible, and will indicate how well a company is able to develop only configuration choices which are beneficial.

Furthermore we propose a metric for the skewness of the distribution of profitability **(CVPS)**. A positive skew will indicate that a few configuration variables are very profitable, whereas a negative skew would indicate that a number of configuration variables contribute significantly to a lower profitability.

All of the data required to calculate the metrics defined within this category are usually obtainable from a company's configuration system and ERP system

4.2 Utilization

This category addresses how well the solution space is utilized by the customers, i.e. how much variety is offered vs. how much does actually make sense compared to the customers' requirements. This is what the metric defined by Piller [14] (referenced from [1]) called Used Variety **(UV)** is intended to measure:

$$UV = \frac{\text{Number of perceived variants}}{\text{Number of all possible variants}} \quad (3)$$

However, using this metric may be difficult in practice, since the number of perceived variants is not readily available. A more practical way of assessing the utilization would be to calculate the frequency by which each configuration variable is chosen by a customer. By dividing this by the frequency of which configurations are made in general, the percentage of configurations containing a certain configuration choice could be calculated, thereby describing the utilization of a certain configuration variable. If these percentages are analyzed statistically, two metrics can be derived: Mean Configuration Variable Utilization Percentage (**MCVUP**) and Configuration Variable Utilization Percentage Variance (**CVUPV**). These two metrics can provide insight into the magnitude and differences in frequently by which certain parts of the solution space are actually creating value for customers.

4.3 Variety Demand Satisfaction

Measuring to what extent the variety offered by a company satisfies the demand for variety is very difficult to measure directly, since this would require immense amounts of data and possibly large customer surveys. However, Blecker [1] presented a number of metrics that are influenced by how satisfied customers are with the variety offered:

Sales are intuitively a metric that can be used to indicate how happy customers are with the variety offered by a company. However, sales can be influenced by many other factors than the solution space, e.g. marketing efforts, sales processes, pricing decisions etc.

We do however believe that it can give some kind of indication.

The metric Repurchase rate **(RR)** [14] describes to what extent customers repurchases a product, or to what extent customers return to the MC company to buy another product. If customers repurchase products regularly, it is reasonable to assume that those customers have been happy with the variety and the product in general. Otherwise they would likely have chosen a competing product instead. The repurchase rate is defined as:

$$RR = \frac{number\ of\ repurchases}{total\ number\ of\ purchases} \qquad (4)$$

A high repurchase rate can be interpreted as an indicator for high customer satisfaction with the product offerings, including variety. Clearly, the repurchase rate does only make sense for products which are purchased frequently, e.g. customized muesli or shirts, whereas products like cars or houses are purchased less frequently by the same customer, rendering this metric irrelevant.

The metric configuration abortion rate **(CAR)** [1] can also be a measure of how satisfied the customers are with the offered variety. Configuration abortion rate is defined as:

$$CAR = \frac{number\ of\ aborted\ configurations}{number\ of\ initiated\ configurations} (5)$$

If a customer initiates a configuration and is not able to select the desired product properties, and is thus unsatisfied with the offered variety, that customer is likely to abandon the configuration and purchase a competing product. Hence, a high abortion rate could indicate that customers are dissatisfied with the offered variety and vice versa.

4.4 Architecture

The product architecture is very central in solution space development, since a good product architecture will greatly reduce development and manufacturing costs when increasing variety, whereas a suboptimal architecture will imply rapidly increasing costs when increasing product variety. Simply put, the product architecture allows efficient generation of product variants and this also indicates how efficienct a company is at solution space development.

Covered extensively in literature, several relevant metrics were found in the literature review. The multiple use metric **(MU)** indicates how many modules are required to produce all variants within the solution space [5]. This metric is defined as:

$$MU = \frac{NV}{NM} \qquad (6)$$

NV is the number of product variants required by customers and NM is the number of different modules required to build all variants in the product portfolio. While number of different modules should be easy for any company to determine, the number of variants required by customers is less trivial. Instead of using this figure, the theoretical total number of product variants could be used. However, as mentioned previously in this paper, this figure may soar to astronomic numbers, rendering the metric less useful.

The modules commonality metric **(MCM)** [1] is a measure of how many modules are common to all variants relative to the total numbe of different modules. This metric is defined as:

$$MCM = \frac{Number\ of\ common\ modules}{Total\ Number\ of\ different\ modules} \qquad (7)$$

Generally a higher module commonality will indicate a more efficient product architecture, since higher commonality will usually imply lower manufacturing and development costs. A metric for parts commonality **(PC)** [1] is used to measure the relationship between common parts and the total number of different parts in the same way as the module commonality metric. A high part commonality also indicates an efficient product architecture since that would imply higher purchasing volume for each different part further implying lower purchasing costs.

In most mass customization companies, these metrics should be trivial to calculate as the necessary data should be available in product documentation and the ERP system.

4.5 Responsiveness

The metrics within the responsiveness category are intended to measure how fast a company is able to develop its solution space e.g. in response to changed market requirements. The first metric is the rate of which new configuration attributes are introduced **(RNCA)**. This is determined by summing up the number of added configuration choices during a certain period. Similarly, the number of eliminated configuration attributes should be measured resulting in the metric **(RECA)**. A high RNCA indicates that a company frequently introduces new options for customers and would indicate that the company reacts to a broad spectrum of changes in the market. A large difference between RNCA and RECA would indicate that the solution space is either growing or shrinking. A steadily growing solution space could indicate a problem, since the company may be focusing on introducing new variety without doing "housekeeping" and eliminating options not needed anymore. This could result in unnecessarily increasing manufacturing complexity.

The two metrics described above describe the change rate of the solution space, but not the lead time for changes, which is also essential when competing in a rapidly changing market. We therefore introduce a new metric called average lead time for configuration variable changes **(ALCVC)**. This metric is defined as the time from a the need for adding or removing a configuration variable is recognised until it is fully implemented. Ideally this metric should indicate the time from an external factor in fact changes until the response in form of a change in the solution space is implemented. However, since data is needed to calculate the value of the metric, in practice the time is measured from the change request is registered in e.g. an ECM or PLM system until it is fully implemented. Hence the time from an external factor changes until this is recognized and registered in e.g. an ECM system is not included in this metric.

5. CONCLUSIONS & DISCUSSION

Based on an analysis of the characteristics of an optimal solution space requirements were formulated to establish a number of metrics for assessing a solution space and companies' ability to perform solution space development. To establish these metrics, relevant literature was reviewed and several applicable metrics were identified. Further metrics were developed in areas where no sufficient metrics could be identified in literature. The following list compiles the identified and newly defined metrics within five areas:

Profitability:

- Aggregate solution space profitability **(ASSP)**
- profitability per product family **(PFP)**
- configuration variables (percentage) having negative profitability **(NPCV)**
- Configuration variable profitability skewness **(CVPS)**

Utilization

- Used Variety **(UV)**
- Mean Configuration Variable Utilization Percentage (**MCVUP)**
- Configuration Variable Utilization Percentage Variance (**CVUPV)**

Variety Demand Satisfaction

- Sales
- Repurchase rate **(RR)**
- configuration abortion rate **(CAR)**

Architecture

- The multiple use **(MU)**
- modules commonality **(MCM)**
- parts commonality **(PC)**

Responsiveness

- rate of which new configuration attributes are introduced **(RNCA)**
- number of eliminated configuration attributes **(RECA)**
- average lead time for configuration variable changes **(ALCVC)**

It is the intention that these metrics can be used to in MC companies for different purposes. One purpose is benchmarking against "best practice" mass customizers, in order to identify areas with the greatest potential for improvement. Another purpose is to use these metrics as key performance indicators which are continually calculated to monitor performance to continuously improve.

In relation to research in mass customization it is the intention to apply these metrics in different types of mass customization companies to analyze what distinguishes successful mass customizers.

It is evident that the application of these metrics poses certain requirements related to data availability and quality. However, most MC companies already have systems in place which are very likely to contain the data required for calculating the metrics presented in this paper.

As mentioned in the introduction, solution space development is one of three fundamental capabilities for successful mass customizers; the other two being robust process design and choice navigation. There are strong relations between these three capabilities, and phenomena experienced in a company cannot necessarily be attributed to only one capability, and as such, the metrics defined in this paper can also be influenced by other factors than the solution space development capability. If for instance the profitability of the solution space changes, instead of changes in the solution space, it could be due to changes in the manufacturing processes lowering manufacturing costs or changes in choice navigation leading customers to choose products sold at a greater price. Another example is the metric configuration abortion rate which we argue indicates how well the solution space reflects the demand for variety from customers. However, the configuration abortion rate will be strongly influenced by the choice navigation, i.e. how well the configurator is implemented. In future research, metrics for the other two capabilities, Robust Process Design and Choice Navigation should be established and the links between all three capabilities can be analyzed. Furthermore, the relations between metrics performance and specific methods should be addressed so that an assessment could point out not only what a company should do to improve but also how.

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CORRESPONDENCE

Thomas Ditlev Brunoe
Ph.d., Assistant Professor
Aalborg University
Dept.of Mechanical
and manufacturing Engineering
Fibigerstraede 16
9220 Aalborg Øst
tdp@m-tech.aau.dk

Kjeld Nielsen
Ph.d. Fellow
Aalborg University
Dept.of Mechanical
and manufacturing Engineering
Fibigerstraede 16
9220 Aalborg Øst
kni@m-tech.aau.dk

Kaj A. Joergensen
Aalborg University
Dept.of Mechanical
and manufacturing Engineering
Fibigerstraede 16
DK-9220 Aalborg, Denmark
kaj@m-tech.aau.dk