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Published in:
Enabling Manufacturing Competitiveness and Economic Sustainablility, Proceedings of the 5th International Conference on Changeable, Agile, Reconfigurable and Virtual Production (CARV 2013)

DOI (link to publication from Publisher):
10.1007/978-3-319-02054-9_28

Publication date:
2014

Document Version
Early version, also known as pre-print

Citation for published version (APA):
Nielsen, K., & Brunø, T. D. (2014). Mass Customisation Assessment and Measurement Framework. In M. F. Zaeh (Ed.), *Enabling Manufacturing Competitiveness and Economic Sustainablility, Proceedings of the 5th International Conference on Changeable, Agile, Reconfigurable and Virtual Production (CARV 2013)* (pp. 165-170). Springer. https://doi.org/10.1007/978-3-319-02054-9_28

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Abstract

Mass customisation involves three fundamental capabilities: Robust Process Design, Choice Navigation and Solution Space Development. A Survey has indicated that a number of companies have ceased mass customizing less than one year after initiating the effort. One reason for this is poor knowledge about the mass customisation progress and guidance of continuous improvement. This paper will conceptualize a framework for measurement and assessment of a company's mass customisation performance, utilizing metrics within the three fundamental capabilities. By assessing performance companies can identify within which areas improvement would increase competitiveness the most and ultimately enabling more efficient transition to mass customisation.

Keywords:
Mass Customisation; Assessment; Metrics; Capabilities

1 INTRODUCTION

To address the increasing customer demand for individually customized products, mass customisation has been widely adopted as a competitive business strategy during the last two decades [1-4]. Many companies have experienced that the implementation of MC is much more complicated than immediately anticipated and in some cases even jeopardized the existence of the company instead of increasing competitiveness. Meanwhile others like DELL, BMW, and ADIDAS have shown that success is indeed feasible [4].

The reason why shifting to mass customisation is so difficult is that it is fundamentally different from mass production. In product development, families of products must be developed instead of individual products. In the sales process, vast amounts of information must be exchanged between customer and company to configure the right product and allow the company to manufacture it. In manufacturing, products are manufactured in batches of one as opposed to mass production where batches are hundreds or thousands of identical products. This basically renders a mass production system useless in relation to mass customisation manufacturing. In relation to logistics, a specific product must be moved from the manufacturing facility to the end customer, whereas in mass production a number of products are shipped from the manufacturer to a warehouse to a retailer where it is sold to the end customer. This further introduces a challenge since mass customisation products cannot be stocked and can only be produced once a customer order is given. All the challenges described above need to be addressed if a company wishes to pursue an mass customisation strategy, which in many cases has proven more difficult than anticipated.

Due to the large difference in success for companies implementing mass customisation, analyses and method development has been addressed extensively in literature [5,6],[7]. Much research has focused on identifying the different enablers for achieving mass customisation and Silveira et al. [6] and Fogliatto [7] present an overview of the research into mass customisation enablers, which is by Fogliatto et al. [7] divided into the categories: 1) Methodologies, 2) design processes, 3) manufacturing processes, 4) supply chain coordination, 5) manufacturing technologies and 6) information technologies.

As pointed out above, manufacturing system flexibility is essential in mass customisation. It has also been generally acknowledged that a reconfigurable manufacturing system is an important enabler for mass customisation [8]. A reconfigurable manufacturing system is according to Koren et al. (1999) [9] a manufacturing system with adjustable structure allowing for scalability according to market demand as well as adaptability to new products. Since the aim of reconfigurable manufacturing system is to possess the capacity and flexibility needed when required [10], this manufacturing system type is highly relevant in relation to mass customisation [11]. Since mass customisation markets are typically dynamic and a continuous development of the solution space for products must be developed over time [4], the need for reconfigurable manufacturing systems compared to flexible manufacturing systems is further emphasized.

1.1 Mass Customisation Capabilities

Recent research has shown that the ability to transform a business into a successful mass customisation business depends primarily on

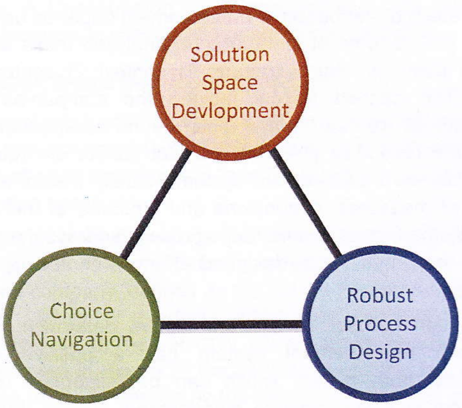

Figure 1: Mass customisation three fundamental capabilities [1].

M.F. Zaeh (ed.), *5th International Conference on Changeable, Agile, Reconfigurable and Virtual Production (CARV 2013), Munich, Germany 2013*,
DOI: 10.1007/978-3-319-02054-9_28, © Springer International Publishing Switzerland 2014

three fundamental capabilities [4,12] (Figure 1): 1) Robust Process Design – *Reusing or recombining existing organizational and value chain resources to fulfil a stream of differentiated customer needs*, 2) Solution Space Development – *Identifying the attributes along which customer needs diverge* and 3) Choice Navigation – *Supporting customers in identifying their own solutions while minimizing complexity and the burden of choice*. Robust process design, as termed in that research, is obviously closely linked to reconfigurable manufacturing systems. Robust process design is somewhat broader defined than only the manufacturing processes, since robust process design also involves business processes and logistics processes.

A company mastering each of the three capabilities will thus have increased chances of succeeding as a mass customizer [4]. Hence, in order to successfully implement mass customisation, companies must not only be capable of robust process design and thus the development of reconfigurable manufacturing system, but also the two other capabilities.

Although these three capabilities are identified and described theoretically in literature, mass customisation firms are still faced with a challenge when evaluating their capabilities to identify where performance lacks since no integrated method is available serving this purpose.

The objective of this research is to identify the relations between mass customisation tools and methods, mass customisation capabilities, the sales and operations in a company and ultimately the profitability and thereby competitiveness of the company. Furthermore the aim is, by identifying these relations, to be able to measure a company's performance within each capability and thereby indicating which tools and methods should be applied with the greatest improvement as a result.

1.2 Mass Customisation Performance Measurement

Performance measurement has long been applied as a tool for improving performance, and since tools like the balanced scorecard have emerged, focus within performance measurement has to some extent shifted from purely financial measures to non-financial measures [13]. Many publications indicate that performance measurement does in fact improve performance; the evidence has been much discussed in literature [14]. It has proven a tremendous tool for assisting in improving performance, performance measurement itself cannot guarantee performance improvement, since the effect of performance measurement depends on a number of factors [14]. Bourne et al. (2005)[14] analysed these factors and organized them into three groups: 1) context 2) content and 3) process. The context factors include the companies' external environment as well as internal factors such as structure, culture, strategy and resources [14]. The content factors are related what the performance measurement system actually measures, i.e. the definition of measures, dimensions and structure of the measures [14]. Finally the factors related to the process address the process in which the measures are 1) designed, 2) implemented, 3) used and 4) refreshed.

Hence a high number of different factors determine whether a performance measurement system has a positive effect on performance, both factors which can be influenced during the development of a performance management system, but also the contextual factors.

Relating this to a mass customisation context, a performance measurement system for mass customisation should be designed with these different factors in mind, but it also implies that one single performance measurement system will not fit all mass customisation companies, since these companies will have different contexts. However, literature generally agrees that performance measurement systems should be aligned with the companies' strategies [13].

In order to develop the three fundamental mass customisation capabilities described by Salvador et al. [4], performance measurement is considered an important enabler, however the performance measurement system must be developed specifically to fit mass customisation and for a specific mass customisation company to be effective. In this research we look into the specific content, rather than context and process of performance management systems to address the three fundamental capabilities.

In the research presented in this paper we identified the metrics needed to develop a performance measurement system for mass customisation, assuming this will be a valuable tool for companies to be able to establish themselves as mass customizers or for existing mass customizers to improve performance. The research question is:

What metrics can be used to measure performance and thereby assess capabilities for choice navigation, solution space development and robust process design and how can these be determined?

The research question has been answered through first defining each capability, and in overall terms, what should be assessed. Then a literature review is conducted to identify related metrics already defined in literature. These metrics are evaluated, whether they are descriptive in relation to the choice navigation, and a final set of metrics is developed for each capability. In previous papers, thorough literature reviews have been conducted and metrics defined in greater detail [15-18]

2 METRICS

The metrics for assessing a company's mass customisation progress as well as their development of capabilities need to reflect the process. 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 mass customisation companies have information systems which could support this, such as configurators, Product Lifecycle Management (PLM) systems, Enterprise Resource Planning (ERP) systems, Engineering Change Management (ECM) systems etc., which we expect would provide most of the required data.

2.1 Choice Navigation Metrics

The choice navigation capability is related primarily to the capabilities of the configuration system, and its ability to configure a variety of products. The customer experience from a product configuration process should aim for a result where the customers recognize that the configuration process supports the customer's requirements and offers the products which fulfil the customer's exact needs [4].

Supporting the customer in the process, making the product configuration easy and fast, is a matter of making it easy to match characteristics of needs, empower customer in building models of needs or embed the configuration in the product [4], from an assessment point-of-view this is potentially measurable. Measuring how well the choice navigation ensures a 100% fit between customer needs and the goods configured by the customers however seems more difficult. Using set theory we have defined and introduced sets to identify areas of interest and potential measurable areas. For assessment of choice navigation 3 sets have been defined and 6 areas of interest have been identified (Figure 2)

Analysing Figure 2, intersections B and C are consequences of a mismatch between the actual demand and solution space, where B implies variety which is part of the solution space but has no demand thus potentially implying unnecessary complexity costs. C implies a demand for variety that is not met by the current solution space and which may indicate an intersection where the development of the solution space could increase sales. The D intersection is seemingly less interesting in terms of choice navigation, since they relate primarily to the capabilities within solution space development.

In intersection D the customer configures a product that does not meet the demand nor is it contained in the solution space. This is not a typical situation but is nevertheless undesirable, and would likely be indicated by the customer abandoning the configuration. In intersection E, there is a match between the variety offered by the company and the customer demand; however the customer does not configure the product. This is likely a result of a user interface unable to guide the customer satisfactory through the configuration process. Intersection F indicates configuration which match a customer demand, but is outside the actual solution space, i.e. a product that can be configured but not produced. Finally, in intersection G the customer configures a product that is within the solution space but does not meet the demand thus resulting in a customer disappointment.

The description of the sets CC, CDV and SS above has been used as criteria for evaluating and developing different metrics used for assessing choice navigation capabilities, since metrics indicating variety outside SS∩CDV∩CC (Area A) will indicate sub optimality.

In order to evaluate which metrics are usable for evaluating choice navigation capabilities, the different set intersections illustrated in Figure 2 have been addressed individually. For each intersection, it is evaluated which metrics can support the assessment.

In intersection E the customer will start to configure a product, but never reach a final configuration which is purchased, although the solution space supports the requirements. This is difficult to distinguish from the case where requirements cannot be met within the existing solution space (intersection C), however it has been found that a high configuration abortion rate (CA) [19] metric can be used as an indication since customers that cannot configure a product to meet their requirements will likely abandon the configuration.

In intersection F the customers configure products which are within the customer demanded variety but outside the solution space, i.e. a product is configured which cannot be delivered. This would likely result in the order being cancelled by the company, since it cannot be manufactured. Alternatively, the company will change the configuration to fit within the solution space by e.g. upgrading the product. High values of Seller Order Cancellation rate (SOCR) [18] and Seller Order change rate after purchase (SOCRAP) [18] would indicate configurations within intersection F.

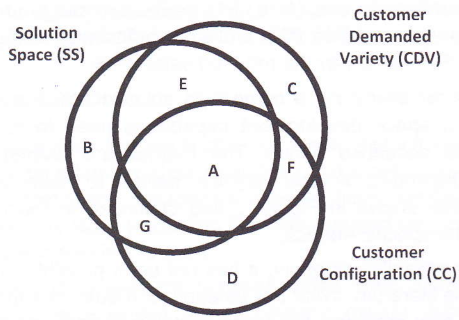

Figure 2: Intersection of Solution Space, Customer Demanded Variety and Customer Configuration [18].

In intersection G the customer configures a product which is within solution space but does not correspond to the customer's requirements. In this case several things could happen. If the customer realizes that the product is not satisfactory prior to delivery, the customer may cancel the order or change the configuration which could be expressed as Customer Order Cancellation rate (COCR) [18] and Customer Order change rate after purchase (COCRAP) [18]. In other cases, customers will not realize that the configured product does not meet requirements, until it is received. In this case the customer may return the product which could be found as Customers Return Rate metric (RTR) [20] or complain (indicated by Customers Complaints Rate metric (COR) [19]). Also repurchase rates (RR) [20] metric and churn rates (CR) [5] metric would be expected as indicators. Configurations within intersection G are found to be indicated by high values of COCR, COCRAP, RTR, COR, and CR and low values of RR.

In intersection D the customer configures a product with properties that the customer does not have a demand for and is not part of the solution space. In this case either the customer or the company can react to this and either cancel or change the order. Hence configurations in intersection D will be indicated by High values of SOCR, SOCRAP, COCR and COCRAP. It may however be difficult to determine whether high values of SOCR and SOCRAP are due to configurations in intersection D or F. On the other hand, the customer does not receive the product no matter which are the configuration is in, so whether the customer had a demand for the product may be less important.

Since configurations within intersection A should lead to a sale, then an increase in Configuration sales rate metric (CSR) [18] would indicate an increase in configurations within intersection A.

2.2 Solution Space Development Metrics

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 a mass customisation company, defined as the set SS (Solution Space) [16] and 2) the variety of products which are demanded by the customers, defined as the set CDV (Customer demanded variety) [16]. As illustrated in Figure 2, the intersection of the two sets will represent the products offered by the mass customisation company which correspond to products demanded by customers. The intersection of the two sets (A∩E) 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.

The metrics for assessing a company's solution space as well as their solution space development capabilities need to reflect the requirements described above. The metrics are divided in five categories depending on what they are intended to measure. These categories are shown in Figure 3 and described in the following along with the specific metrics.

Within the profitability category, it has not been possible to identify metrics in the literature. What this category of metrics is supposed to measure is how profitable the mass customized products are. The reason why 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 has been defined: Aggregate solution space profitability (ASSP) [16] is a measure of how profitable the solution space is as a whole and should be measured over a period of time, a metric measuring profitability per product family (PFP) [16], calculated similarly over a period of time and metric for Configuration Variable Profitability (CVP) [16], 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 [21]. What is also interesting is how many configuration variables (percentage) have negative profitability (NPCV) [16]. Obviously, this metric 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) [16]. 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.

The utilization 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 [20] (referenced from [19]) called Used Variety (UV) is intended to measure. 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 analysed statistically, two metrics can be derived: Mean Configuration Variable Utilization Percentage (MCVUP) [16] and Configuration Variable Utilization Percentage Variance (CVUPV) [16]. 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.

Sales are intuitively a metric that can be used to indicate how satisfied 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

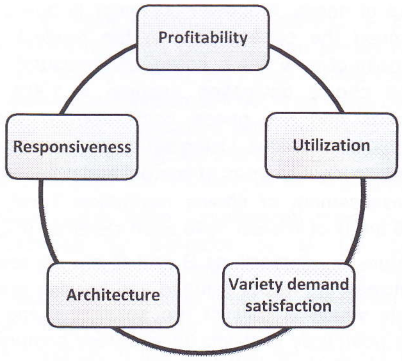

Figure 3: The five categories introduce to measure Solution Space Development.

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

The metric Repurchase rate (RR) [20] describes to what extent customers repurchases a product, or to what extent customers return to the mass customisation company to buy another product.

The metric configuration abortion rate (CAR) [19] can also be a measure of how satisfied the customers are with the offered variety. 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.

The product architecture is very central in solution space development, since 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 efficient 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) [22] indicates how many modules are required to produce all variants within the solution space. However, as mentioned previously in this paper, this number may soar to astronomic numbers, rendering the metric less useful.

The modules commonality metric (MCM) [19] is a measure of how many modules are common to all variants relative to the total number of different modules. Generally a higher module commonality will indicate more efficient product architecture, since higher commonality will usually imply lower manufacturing and development costs. A metric for parts commonality (PC) [19] 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.

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) [16]. 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) [16]. 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. 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) [16].

2.3 Robust Process Design Metrics

The most postponed manufacturing setup is expected to support highly robust manufacturing processes. A good indicator of robust process design is differentiation Point Index (DPI) [23]. The Setup Index (SI) [23] addresses the cost of setup of manufacturing processes compared to the total cost of a product, and is an indicator of a low robustness.

Metrics have been identified which are related to time performance of the manufacturing system, i.e. the Quality of Order Reception (QOR) [24], the Order Delay Time (ODT) [24] and Customisation Process Indicator (CPI), the latter indicates the relationship between the actual manufacturing time of a customized product and the time a customer is willing to wait for a custom product [24]. Although these metrics are not direct indicators of process robustness, it is expected that highly robust manufacturing processes will have a good time performance and good performance within these metrics will indicate robust processes.

The metric Number of different modules manufactured per process (NMP) [17] gives a measure of the average number of modules manufactured in the different manufacturing processes; a higher NMP will indicate robust processes, since each process will be able to manufacture more different modules and thus a higher number of end variants.

The metric Degree of manual labour (DML) [17] can be used as an indirect indicator of process robustness, since a low need for manual processing will indicate that the non-manual manufacturing processes are able to supply a high variety.

Setup Index (SI) is the cost of setup of manufacturing processes is considered good measures of process robustness towards new variety. Process variety increase (PVI) [17] indicates how much the variety of manufacturing processes increases when a new product option or product is introduced in the manufacturing system. The PVI metric, calculated as an average during a period in time, a low PVI will indicate a high robustness since this implies that few new processes need to be introduced when a product option is introduced and thus that the existing processes can accommodate new product variety. The capacity expense (CAPEX) increase when introducing a new option is introduced (CAPIV) [17]. This is done since a high PVI does not necessarily come a high cost, given a new process is implemented on existing flexible equipment. The CAPIV metric is calculated as an average over a period of time.

The time and cost to introduce new product variety are also important metrics to assess process robustness, since robust processes will imply low cost and fast introduction of new product variety. The metrics Time to introduce a new option in the manufacturing system (TIV) [17] and Cost of introducing a new option in the manufacturing system (CIV) [17] have been defined.

3 DISCUSSION

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

There are strong relations between these three capabilities, and phenomena experienced in a company cannot necessarily be attributed to only one 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.

One example is the metric configuration abortion rate which we argue indicates how well choice navigation is implemented. However, the configuration abortion rate will be strongly influenced by the solution space, i.e. how well the offered variety matches the demanded variety. In future research the relationship between the capabilities should be established and the links between all three capabilities need to be analysed. 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.

When performing an assessment and interpreting the values of the metrics, the interpretation should take into account the product type. Also when benchmarking, companies manufacturing different products cannot necessarily be compared directly. The reason for this is that several metrics are based on the customers' actions, and these actions will depend on the product type. For example a customer buys a customized car compared to a customized bag of muesli, the customer would probably then be more likely to complain or return the car if it has a wrong colour compared to the muesli, if a wrong ingredient has been added. In that case, the difference would be due to the difference in cost of the products. Furthermore a metric like the repurchase rate makes more sense for some product types than others. For example, customers are likely to repurchase muesli more often than cars. So this metric would depend on to what extent a product can be characterized as a consumable or a durable, and in case it is a durable, how long the life cycle is.

4 CONCLUSION

In order to support the development of production in mass customisation, metrics are needed in order make performance measurement, assessment and benchmarking. To establish these metrics, relevant literature has been reviewed and several applicable metrics has been identified. Further metrics have been defined in areas where no sufficient metrics could be identified in literature.

In relation to research in mass customisation it is the intention to apply these metrics in different types of mass customisation companies to analyse what distinguishes successful mass customizers. It is the intention that these metrics can be used in mass customisation 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.

This work concludes a preliminary research of assessment and measurement of the mass customisation process. We have with this paper finalized a general approach how to assess and measure mass customisation and set a framework of potential metrics, whether this is for the purpose of internally performance indicators or it is used for benchmarking in general. The next stage in this research will be test and evaluation of these potential useful metrics.

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