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Performance measures for mass customization strategies in an ETO environment

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Abstract

When following mass customization (MC) principles, manufacturing companies have to consider several aspects. Complexity is thereby seen as a major challenge to be handled. Especially for ETO companies the movement towards MC is much more complex, as products are not standardized, processes are seldom automated and little control over the customer portfolio is obtained. Based on case studies, this research proposes a new way of effectively and efficiently implementing MC strategies. It closely investigates deviations between contribution margins and between pre- and post-calculations of operational measures. The results show the negative impact of high deviations on the corresponding performance.

Keywords: Performance Measurement, Complexity Management, Mass Customization

Introduction

The competitive strategy of mass customization (MC) is recognized as an effective means for manufacturing companies to achieve sustained advantage in a global market competition (Kumar, 1994). It combines the two traditional manufacturing practices of mass production and craft production (Duray, 2002) with the aim to enable companies to provide custom tailored products with nearly mass production efficiency (Tseng and Jiao, 2001). In the last two decades, a vast amount of research has presented the implementation of MC principles (Blecker et al. 2005). Pine (1993) in particular popularized the concept of MC by introducing five fundamental methods concerning the conversion from mass production to MC. Other less common approaches describe how standardization (Kubiak, 1993) and the use of common technology platforms (Pine et al., 2009) facilitated the transformation of engineering oriented manufacturers from an individual customization to a partly MC.

In general, manufactures offering bespoke products which are engineered to the specific requirements of a customer are by definition characterized as engineer-to-order (ETO) companies (Wilkner and Rudberg, 2005). Even though such ETO firms obtain very different characteristics compared to mass producers (Caron and Foire, 1995), their motivation and challenges when perusing MC strategies have seldom been discussed. According to Haug et al. (2009) four principle aspects have thereby to be considered. ETO companies should inter alia focus on reducing the product variety and on creating

an adequate customer variety. Despite the clear formulation, the authors, however, omit to describe how these objectives are to be pursued.

The emphasis of this research is therefore to identify suitable valuation methods which initially assess the current performance of ETO companies moving towards MC. Once successfully completed, such a performance analysis should be capable of specifying how the previously defined objectives towards the implementation of MC strategies are to be achieved. Based on a literature study, first existing concepts and aspects of MC are examined. To evaluate the implementation of MC, additional performance measures are defined. Eventually, a conceptual framework is introduced that strives to better meet the requirements for the intended assessment. The framework is finally tested on three industrial case studies.

Research methodology

A widely used approach for assessing the financial and operational status of a company and monitoring its development over time is to introduce relevant performance measures (Kaydos, 1999). Such measures can be seen as a metric for quantifying the efficiency and effectiveness of an action, where performance measurement describes the process of quantification (Neely et al., 2005). In order to test the analysis method, several case studies of ETO companies are performed. Since full access to detailed data within each company is given, validity of the research findings can be created through an in-depth investigation. To enable a comparison across the studies and thus to achieve external validity (Yin, 2003), each case study preferably follows the same performance measurement approach. Rigor of data collection is insured through foregoing qualitative methods (e.g. unstructured and semi-structured interviews). Subsequently, quantitative data is collected and analysed by means of the proposed methodology.

Literature review

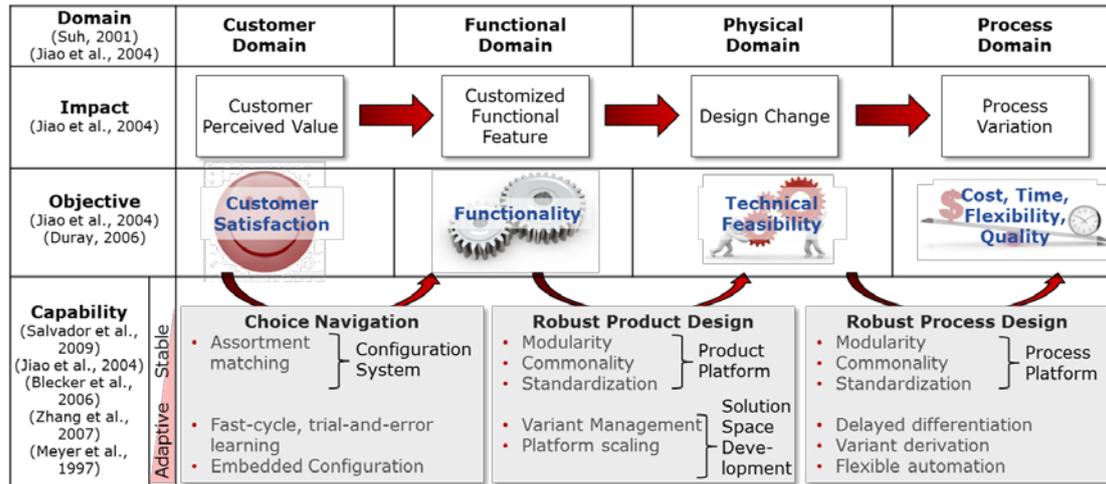
Background and perspectives of mass customization

Over the past three decades, various strategies and frameworks for defining and characterizing MC have been proposed (Da Silveira et al., 2001). Due to its broad application along the value chain of organizations, literature has been dealing with diverse aspects of the MC concept. While some of the research has been investigating the business and marketing implications of MC, others have examined its impact on operations, product development, manufacturing and supply chain (Fogliatto et al., 2012). For the purpose of this study, we will focus your research on the impact of MC of physical products on the different domains of a company, as proposed by Su (2001), disregarding other areas such as the supply chain coordination, as e.g. discussed by Chandra et al. (2004).

According to Jiao et al. (2004), when customizing products the entire product realization process is affected. As illustrated in Table 1, such a process can e.g. be described based on Su's domain framework (Su, 2001). From the customer domain, customer satisfaction is achieved by a given customer perceived value. This value can be realized by customized functional features in the functional domain, which in turn generate a design change in the physical domain and a variation of processes in the process domain. The objective for the functional domain is to achieve customer satisfaction through a well matching functionality of the product. In the physical domain, technically feasible design solutions are fulfilling the functionality requirements of the requested customization. Eventually, the customized design is realized under the time and cost restrictions of the process domain. Besides, it can be argued that high quality and flexibility should likewise be pursued for efficiently fulfilling of the requested customization within the process domain. After all flexible and reliable processes that quickly adapt to a given

customization order are crucial for the operational performance of mass customizers (Duray, 2006).

Table 1 - Multiple views of customization



Generic capabilities of mass customization

In order to achieve the abovementioned objectives of the domains, researchers have proposed several enablers or capabilities in support of an effective implementation of MC. Based on an extensive literature review, Fogliatto et al. (2012) for example agree, that certain product, process and order elicitation methods and technologies considerably enhance the way how customization is fulfilled within organizations. Their investigation shows that the use of product configuration systems combined with data mining helps to efficiently identify and translate customer requirements into the functionalities of a product. A configuration system is a subtype of knowledge-based expert systems. It represents the product knowledge relevant to the customer (product features) in a formal way, allowing a complete definition of possible product outcomes (customized functional features) with a minimum of entities (Hvam et al., 2011). With the implementation of product platforms, companies can then achieve efficient variety management, as they translate the customized functional features into the design changes (Jiao et al., 2004). Meyer et al. (1997, p. 39) define a product platform as “a set of subsystems and interfaces that form a common structure from which a stream of derivative products can be efficiently developed and produced”. Process platforms on the other hand represent a set of (production) processes that form predefined bill-of-operations and thereby enable the completion of process variations for a given customer order (Jiao et al., 2004). The coordination between the process elements and the ordered product elements can be called variant derivation (Zhang et al., 2007). In order to reduce the complexity caused by the increase of product and process variety, a postponement of the unique variants (delayed differentiation) is desirable (Blecker et al., 2006; Forza et al., 2008).

Similarly, Salvador et al. (2009) propose three general capabilities companies should try to develop when pursuing MC: (1) choice navigation, (2) solution space development and (3) robust process design. With choice navigation a mass customizer should assist customers in identifying their requirements and corresponding solutions (product features) while minimizing complexity and the burden of choice. In the solution space development, a set of functionalities has to be defined which represent best the features requested by a wide range of customers. Eventually, through a robust process design

existing organizational and value-chain resources are reused efficiently under the premise of the process domain, i.e. time, cost, quality and flexibility.

While choice navigation and robust process design can readily be combined with the before mentioned MC methods and technologies, solution space development seems to cover only one of the aspects when linking the functional and the physical domain of organizations. Instead, with respect to robust process design, modelled after Taguchi et al. (2000), we propose the term robust product design, where we integrate the concept of a platform based product development with the described solution space development. In Table 1, an overview of the three capabilities is provided, where we further distinguish between a time-independent (stable) and time-dependent (adaptive) aspects of the corresponding MC strategies. For a comprehensive description of each of the categories, we recommend the related references listed in the table. Companies which manage to transact to a large extend all three capabilities are likely to become successful mass customizers (Salvador et al., 2009).

Complexity and transition characteristics for mass customization

With the growing intention in implementing MC, manufacturing companies have to accept major changes within their organization. Since customization shapes the entire product realization process (Jiao et al., 2004), many aspects along the value chain of a product realization have to be redefined. However, the transition process towards MC can be carried out effectively, when the undertaken MC strategies are aligned with the aforementioned generic capabilities. Based on a conceptual perspective, Blecker et al. (2006) introduce a logical sequence for implementing a series of MC strategies. The thereby mentioned strategies can be related to development of two of the generic capabilities, namely a robust product and process design. In order to assess the efficiency of the approach, the authors discuss the impact of each of the strategies based on the complexity level companies have to handle, as defined by Su (2005). In result, implementing the right MC strategies should facilitate the handling of an increasing level of complexity. In a related study Blecker et al. (2005) moreover discuss the relationship between the order taking process (assortment matching) of choice navigation and MC, where configuration systems considerably help to handle the increasing configuration and order taking complexity. Even though not further defined by the authors, as illustrated in Table 2, it is reasonable to assume that successfully implemented choice navigation potentially reduces time-independent complexity and indirectly transforms combinatorial into periodic complexity. When implementing configuration systems, customer requirements thus product features are formally described and further mapped with the offered set of functionalities (solution space). Besides, since the provided product variants have to be configurable, first the structural complexity of the product has to be reduced inter alia through the implementation of modular product architectures (Hvam et al., 2011; Orfi et al, 2011). Other business related studies in contrast discuss the impact of complexity on firms' financial performance (Mahler et al, 2009; Kaplan , 2012; Scheiter et al., 2007). Case studies have thereby been used to empirically validate the effect on costs and earnings before interests (EBITs) from restraining the solution space to the most profitable part of the portfolio. However, the relationship to the other capabilities and complexity types has thereby been neglected.

When comparing the transition towards MC from the two extreme cases of manufacturing set-ups, i.e. mass production (MP) and ETO, several major differences can be seen. One main characteristic relates to the customer order decoupling point (CODP), i.e. the point where the in the manufacturing process a product is associated with a customer order (Wikner et al., 2005). Another aspect discussed by Brunoe et al. (2012)

refers to the solution space development. A mass producer typically has a predefined solution space, which due to the increased customization demand has to be gradually extended when moving towards MC. On the other hand, ETO products are engineered, i.e. individually customized, without any predefined limitations with regard to the solution space. Haug et al. (2009) compare those differences according to several aspects, such as product and customer variety, manufacturing and the use of configuration systems. As illustrated in Table 2, when substituting these aspects with the previously defined major capabilities, the mentioned characteristics can unambiguously be related and further aligned with the broader undertaken approach of MC.

Table 2 - Relationships between capabilities, complexity and characteristics of MC

MC Capabilities		Complexity Type (Suh, 2005) (Blecker et al., 2006)		Transition Characteristics	
				MP -> MC (Haug et al., 2009)	ETO -> MC
Choice Navigation	Initial	Real	Time-independent	Improve user experience	Reduce complexity of knowledge base
				Slight increase of internal variety	Limit internal variety
Robust Product Design	Adaptive	Imaginary	Combinatorial	Create valuable commercial variety	Create adequate commercial variety
	Robust Process Design			Time-dependent	Slight increase of cost, lead times & flexibility
			Periodic		

Research objectives

Having theoretically clarified the principal aspects of an effective MC implementation however doesn't necessary explain how the transition should be realized in practice. To be able to provide a meaningful recommendation, further guidance based on real case studies is needed (Fogliatto et al. 2012). Especially from an ETO perspective, literature describing such transition aspects typically concentrates only on one subpart of the three capacities, for instance on how configuration systems could be used in support of the ordering process (Haug et al., 2009; Haug et al., 2011; Brunoe et al., 2012), leaving out any of the remaining transition characteristics unexplained. In contrast, with this study we aim at identifying suitable performance measures which allow an initial assessment of the industrial case at hand and thereby efficiently direct its transition progress towards MC. In particular we investigate what assessment matrix is suitable for the evaluation of a broad range of transition aspects. Thus the research questions to be answered are:

Q1: What are the critical performance indicators that determine the success of a variety of MC strategies?

Q2: What are the limitations of the resulting performance measurement?

Q3: How can possible recommendations for further action be given based on the chosen performance measurement?

Framework development

In principle, in order to evaluate how successful ETO firms are with their MC strategies, the various domains of customization have to be investigated (Mortensen et al., 2010). While measuring the operational performance, e.g. cost and lead times, is rather common in the MC domain (Su et al., 2005), the financial impact of customization has less been discussed (Duray, 2006; Forza et al., 2008). Alternatively, including both aspects of operations management (Melnik et al., 2004) into a comprehensive measurement metrics could result in a tremendous task that is impossible to be handled. Since such a metrics could then easily contain an unreasonable large number of key indicators

(Kaydos, 1999), one would easily loose focus on the most critical performance aspects. In a case study, Mortensen et al. (2010) point out that especially manufacturers offering ETO products often struggle with significant contribution margin (CM) deviations. Accordingly a considerable high amount of their portfolio generates no or little profit. Assuming that for similar products relatively stable CMs are pre-estimated, such unexpected deviations may result from poorly made cost pre-calculations. Since pursuing MC requires a clear understanding of the relationships between markets, products and processes, more accurate pre-calculations would lead to better aligned activities. In fact, the comparison of planned vs. realized calculations can accordingly be applied to other operational dimensions, such as time and quality. In result, we propose the following hypothesis:

Hypothesis 1 (H1). Investigating deviations between CMs and between pre- and post-calculations of the operational performance reveal potential vulnerabilities of ETO manufacturers moving towards MC, where:

(H1a) high deviations between CMs within a product family; and

(H1b) high deviations between pre- and post- calculations of the related operations; indicate that MC strategies are not aligned.

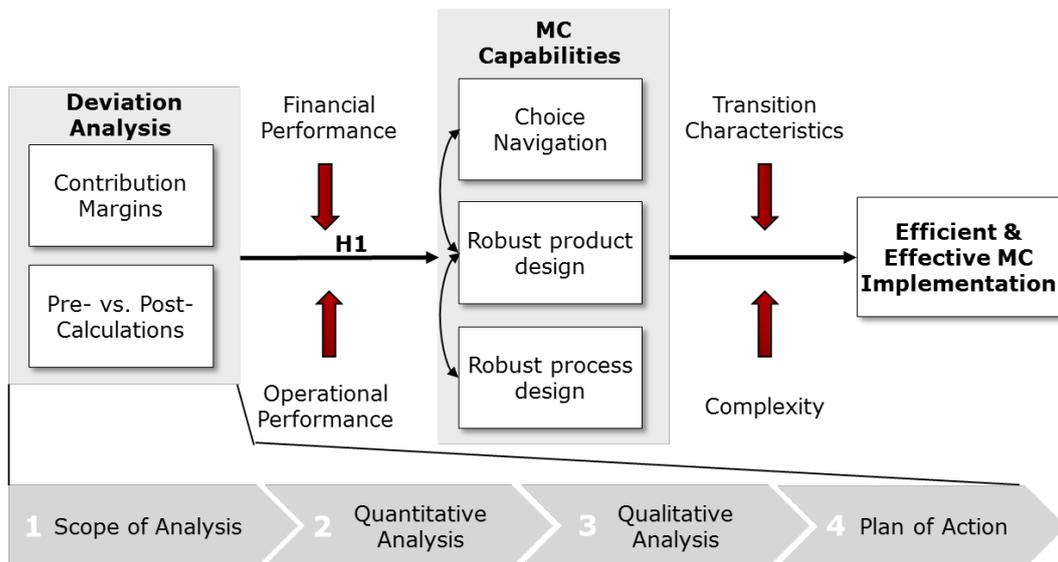


Figure 1 - Conceptual framework for efficient and effective MC implementation

As illustrated in Figure 1, the conceptual framework underlining the hypothesis links the analysis methods with the discussed capabilities, transition characteristics and complexity aspects for an effective yet efficient MC implementation. The analysis of deviations is suggested to be performed in the following four major phases. As a starting point, in Phase 1 the boundaries for analysis can be set by focussing on a limited number of product families and corresponding projects in defined period of time. In accordance with Mortensen et al. (2010), initially the main characteristics of the product family are categorized from an external perspective, where market segments, customers and key product features are identified. To obtain an overview over the stated project performances, in Phase 2 pre-calculations regarding turnover and the related distribution of costs are collected. Marginal (contribution) costing is then used to provide a more realistic picture about how the turnover is distributed throughout the projects. Since only pre-calculated variable costs are considered, loading incorrect overheads onto products can be avoided (Klook et al., 1997). To achieve further insight, turnover and CMs are

related to the identified market segments, customers, product features (Mortensen et al., 2010; Scheiter et al., 2007). The combination of certain aspects thereby potentially indicates causes-effect relationships of the project success. In addition to cost related measurements, planned lead times, promised quality and desired flexibility of processes can be investigated (Neely et al., 2005). However, as for ETO manufacturers some of the information might not be formally available, in some cases it is useful to first conduct a qualitative assessment of the aspects. Interviews with responsible managers may give indication on what measures to focus on at the first place. Since until then the performance analysis is solely based on the pre-calculated figures, in the following steps post-calculations are applied to validate these results. Activity-based costing (ABC) is used to determine the main cost drivers for each project (Cooper et al., 1991). As most typical activities in manufacturing firms involve by definition manufacturing, sales and procurement processes, for the comparison of the results with the foregoing analysis only labour and material recourses are taken into account. Therefore not directly related resources e.g. for administration are not further considered. In case additional operational measures, e.g. lead times, are found to be critical performance factors, they should as well be included in the post-calculation analysis. By comparing deviations between the planned and realized figures, e.g. promised vs. realized delivery time, additional potential drawbacks can be revealed. At the end of this step, major findings are to be summarized and recommendations for further action are to be set. In order to confirm the results and to achieve data triangulation, a subsequent qualitative analysis (Phase 3) is performed. Interviews with the responsible staff help to identify the rationale behind the results and to either verify or falsify the conclusions. The last step of the analysis (Phase 4) involves a plan of action, where major activities for further action are to be defined according to how successful the capabilities of MC have yet been accomplished.

Case description

Data collection and limitations

To provide empirical evidence for the chosen analysis methods, the proposed conceptual framework was applied on three cases studies. Testing the framework on companies which substantially differ in size, industry and product range helped to better understand it's the practical difficulties limitations. However, it also became more challenging to use a consistent analysis approach throughout the case studies. For instance, while for company A on a high level enough information regarding pre- and post-calculated prices and cost was available, for the remaining case companies big part of the data was not documented. Therefore, for the letter cases already at the beginning of the analysis in Phase 1, additional interviews with managers and engineers from in different department had to be conducted. Especially in case of the pre-calculation related to prices and costs, often much of the information depended on the knowledge of experienced individuals, which was neither documented nor formally described. Therefore, as indicated in results in Table 3, for some measure only qualitative estimations could be obtained. This resulted in pre-calculations which later often turned out be rather unrealistic. On the other hand, a smaller company size proved to be beneficial for investigating post-calculations. Data concerning main cost drivers of projects could easier be investigated, while interviews with the responsible managers helped to identify other operational aspects within the organization. For company A the situation was quite different. Having initially analyzed the project performance on an aggregate level, investigating further details concerning the interesting aspects of the analysis turned out to be surprisingly difficult. Data was mainly available on an aggregate level and in additional, individuals

had a less clear understanding of possible cause-effect relationships with regards to the chosen metric.

Table 3 – Abstract of key figures of the cases companies

	Company	A		B		C	
General	Industry	Oil & Gas		Industrial & Manufacturing Security		Construction	
	Turnover [in Mil. €]/ Employees	6000 / 20.000		100 / 600		50 / 250	
Phase 1	Unit of Analysis	1 Product Family		2 Product Families		Product Portfolio	
	Sample Size	12		550		80	
	Turnover [in k. €]/Project	50.000		20		1000	
Phase 2	Contribution Margin (planned)	Mean:	21%	Mean:	25%	Mean:	40%
		STDEV:	11%	STDEV:	5% (qual.)	STDEV:	5% (qual.)
	Contribution Margin (actual)	Mean:	8%	Mean:	21%	Mean:	24,7%
		STDEV:	18%	STDEV:	6%	STDEV:	16,5%
	Main Cost Drivers & Deviations	<ul style="list-style-type: none"> - Production (60%±5%) - Engineering (13%±5%) 		<ul style="list-style-type: none"> - Commissioning (20%±10%) - Project Man. (15%±10%) 		<ul style="list-style-type: none"> - Production (45% ± 13%) - Material (20±25%) 	
Phase 3-4	Main Findings	<ul style="list-style-type: none"> - 50% of the EBIT decrease cannot be explained - Too much resources for repetitive engineering tasks 		<ul style="list-style-type: none"> - High deviation in estimated and actual prices - Unprofitable market segments - High deviation in product quality - Product family inconsistent 		<ul style="list-style-type: none"> - High deviation in project management and engineering - High deviation in estimated and actual prices - High deviation in product quality 	
	Action Plan	<ul style="list-style-type: none"> - Assortment matching - Product standardization - Process standardization - Variant derivation 		<ul style="list-style-type: none"> - Assortment matching - Solution space development - Process standardization - Variant derivation 		<ul style="list-style-type: none"> - Assortment matching - Flexible automation 	

Summarizing the results

Table 3 provides an overview of the conducted case studies in relation to the defined phases. Since company A works with relatively large projects that involve the delivery of whole systems, to be able to perform the analysis within the limited timeframe, a rather small sample size was chosen. On the other hand, bigger sample sizes were used for smaller and simpler projects in company B and C. A general outcome of the analysis for all three case studies is that the planned CM performance of the projects was in average overestimated, while the related standard deviation remained continuously on a lower level. Both figures indicate that for a large number of the projects the case companies continuously plan with inaccurate cost estimations, where for extreme cases negative EBITs were achieved. The realized CMs and post-calculations reveal a less stable picture. As expected, the major cost drivers for the projects are costs related to production. Due to the special business area of company B, a big cost factor accounts for the commissioning of their products. The main findings from three case studies show that even though the actual performance of their projects was less than what the companies initially expected, the causes can be different. While company A and B have inter alia to put more effort in standardizing their processes, company C appeared to have rather stable process design. However, due to the lack of automation and little understanding of the planned costs, several other drawbacks could be revealed. Company B was advised to redefine on the offered solution space and the target market segments, since in

some cases negative EBITs were unintentionally achieved. Finally, in accordance with literature, all of the three case companies could improve the process of assortment matching through the implementation of a configuration system.

Conclusion and further work

When following MC principles, manufacturing companies have to consider a number of aspects. The related complexity is thereby seen as a major challenge to be handled (Blecker et al., 2006). Especially for ETO companies the movement towards MC seems to be much more complex compared to mass producers (Haug et al., 2009). Their products typically comprise a low degree of standardization with no or little commonality, their processes are seldom automated and they have little control over their customer portfolio. The presented research aimed at addressing the various domains of MC, complexity and transition characteristics. To avoid the risk of misunderstandings (Piller, 2004), each of the aspect were discussed and set in relation to one another. By considering various strategies of MC, complexity management, as well as current business practices, the study further considered approaches of how to efficiently and yet effectively implement MC. Eventually, a conceptual framework with adapted performance matrices was introduced. To conform to the identified objectives for ETO companies, the suggested approach closely investigated deviations between CMs and between pre- and post-calculations of operational related measures. The results showed how high deviations of the chosen performance measures had a negative impact on companies' performances. Based on the gained findings, recommendations for a further implementation of MC strategies were given. However, since only a limited number of case studies were conducted, in order to obtain a structured guidance for the proposed analysis and to better understand its limitations, further industrial case studies are needed.

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