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Variety Steering Concept for Mass Customization

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a_i	Value added at process i
A_t	Ideal assembly operation time
AR	Configuration abortion rate
AT_c	Average time for carrying out one change in the configuration system
$AT_{(cc \rightarrow dp)}$	Average time elapsed from configuration until documents preparation
c_i	Cost of set up at process i
C_j	Total cost (material, labor, and overhead) of j^{th} product
$CCR(\Delta T)$	Customers churn rate at ΔT
CI	Commonality index
CODP	Customer order decoupling point
$CR(\Delta T)$	Complaints rate at ΔT
CT	Average configuration length of time
CT_i	Time needed from one customer to fulfill one configuration
CUM	Capacity Utilization Metric
d_i	Average throughput time from process i to sale
d_1	Average throughput time from beginning of production to sale
DI	Differentiation Point Index
DR	Delivery time reliability
E_v	Multiple use metric
$FIC\ (\Delta T)$	Frequency of introducing changes in the configuration system
$GR(\Delta T)$	Growth rate at ΔT
I_c	Interface complexity metric
IL	Integration level of the configurator in the existing business processes
k_i	Number of products, which use the module M_i
L	Lead time
L_i	Weight of the module M_i
m	Number of all modules
M_i	Module i
MCM	Modules commonality metric
MS	Percentage of module suppliers
n	Number of processes

N	Number of fulfilled configurations
N(T)	Number of customizable attributes at T
n_{ij}	Number of modules Mi assembled in P_j
N_m	Number of modules in one average product variant
N_{mt}	Total number of modules required to build up all the product variants
$N_n(\Delta T)$	Number of new introduced customizable attributes at period ΔT
$N_o(\Delta T)$	Number of eliminated customizable attributes at period ΔT
N_p	Number of parts in a complete product
N_s	Number of supplied modules in one average product variant
N_v	Number of product variants required by customers
nc	Total number of changes introduced in the configuration system
$NC(\Delta T)$	Number of changes and data base up dates at a period ΔT
NOC(T)	Number of customers at time T
$NOLC(\Delta T)$	Number of lost customers at ΔT
$NONC(\Delta T)$	Number of new customers at ΔT
NIP	Number of business processes integrated in the configuration system
no	Number of all customer orders
NP	Number of all business processes
p_j	number of parts in model j
P_j	Product variants having used the module M_i
PC	Percentage of potential customers
PCM	Parts commonality metric
PEM	Platform efficiency metric
PPC	Purchasing process commonality metric within a part category
PPCM	Production Process Commonality Metric
$R(T+\Delta T, T)$	Ratio of customizable attributes at t+ ΔT to customizable attributes at T
$R(\Delta T)$	Repurchase rate at ΔT
$RR(\Delta T)$	Return rate at ΔT
S_j	Sales in unit of P_j
SI	Setup cost index
SM	Setup metric
SP	Percentage of standardized parts within a part category
T_a	Average assembly time for one part

T_{c_i} Time required for change i in the configuration system

$T_{(cc \rightarrow dp)_i}$ Time elapsed from the completion of one configuration until documents preparation

t_i Average time needed for a set up at process i

T_i Assembly time for one interface

T_j Lead time for the manufacturing of product j

T_{nva} Average time for non value adding activities

T_t Average time for functional testing of modules

u number of unique part numbers

UVM Used variety metric

$V_{opt.}$ Variety optimum

v_i Number of different products exciting process i

v_n Final number of varieties offered

WIP Work-in-process turnover

δV Value difference across configurations

ΔT Period of time

Abstract

In this paper we make the distinction between subjective and objective customer needs. The subjective needs are the individually realized and articulated requirements, whereas the objective needs are the real ones perceived by a fictive neutral perspective. We show that variety in mass customization has to be orientated on the objective needs. In order to help mass customizers better evaluate the degree to which they can fulfill the objective needs as well as their internal complexity level we have developed a key metrics system model. We also present a conceptual application showing how to use this model to support decision making related to the introduction or reduction of product variants.

1 Introduction

Fulfilling and understanding each individual need is considered as an enormous challenge for companies. Rather than offering market-focused products, which correspond to an average satisfaction of several customer needs, companies that are pursuing the strategy of mass customization strive to offer customer-focused products with a large individuality degree (Pine 1997, p. 3). This means "…that nearly everyone finds exactly what they want" (Pine 1993, p. 44).

However, the strategy of mass customization is associated with high variety leading to high complexity costs (Rosenberg 1997, pp. 87). Two types of variety can be observed, namely external and internal variety. While the former is seen by customers and often but not always good, the latter which is experienced inside manufacturing and distribution operations, is always bad (Anderson 1997, p. 45). A mass customizer has to manage efficiently this variety, in order to avoid a variety explosion (Knolmayer 1999, p. 2).

In addition to the well-known causes of variety such as customer orientation and internal variety regardless of the development of new products (e.g. Lingnau 1994, pp.67, Anderson 1997, pp. 97), the misconception of the real customer needs is considered as the basic cause being responsible for increasing variety while pursuing the mass customization strategy. Chapter 2 presents a theoretical approach supporting this statement as well as some basic principles related to mass customization and variety management. Chapter 3 deals with the description of the main sub-processes in mass customization. The principle key metrics related to variety are then derived. Their importance for mass customization as well as their potential to capture the effects of variety are pointed out. These key metrics are then aggregated in a preliminary model showing how these metrics are connected with each other. Chapter 4 aims at presenting some tools dealing with how to approach the real customer needs. On the basis of these tools the key metrics required to complete the preliminary model are defined and added to the final key metrics model. Chapter 5 presents a theoretical application for variety steering using the final key metrics model. This application shows how to use the key metrics system to evaluate the internal complexity and the degree to which the mass customizer can fulfill the customer real needs.

2 Variety Management and Mass Customization

2.1 Variety Management in a Mass Customization System

The goal of mass customization is to produce goods and services for a relatively great sales market and to simultaneously meet the needs of nearly every customer demand. Costs of these goods and services are comparable to those of mass produced standard products. Furthermore, information arising within the scope of the customizing process serves to build up an everlasting individual customer relationship (Pine 1993, p. 44). Mass customization is also considered as a synthesis of two management systems, which at first glance, seem to be opposites, namely “Mass production” and “individualized customer-specific goods and services” (Rogoll/Piller 2002, p. 11).

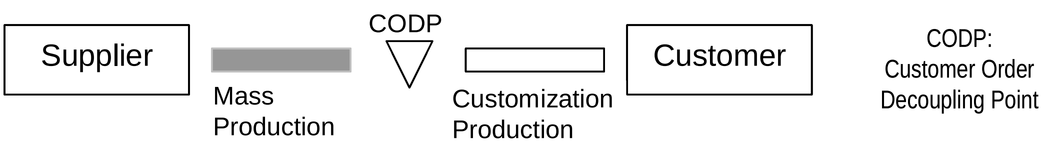
The result of mass customization is a very rich-variant production. A batch size of one is conceivable and means that each produced variant can be a unicum. The resulting variety triggers high complexity and should be efficiently managed. Blecker et al. (2003, p. 22) distinguish between customer-coherent and customer-inherent product configuration. The customer-coherent configuration is characterized by a limited configurational freedom, where customers make choice on the basis of predetermined number of variants. However, the customer-inherent configuration permits an additional configurational freedom and allows constructional product changes within a certain defined scope. Customer-inherent product configuration leads to variety which is still higher and complexity management gains more importance.

Mass customization has a high potential for decreasing costs by reducing finished goods inventory and avoiding special offers. The customer-pull system in mass customization especially improves the planning situation in dynamic markets. Finished goods are not produced until a customer order arrives. Customer integration and interaction are also considered as additional factors capable of decreasing costs. On the other side, higher complexity costs arise. These costs must be reduced to the maximum and permanently kept under the benefit level resulting from the implementation of mass customization (Rogoll/Piller 2002, p. 14).

In order to benefit from the advantages of mass production, it is important for a mass customizer to develop modular products. Products built around modular architectures can be easily varied, while reducing the manufacturing system complexity. For example, Swatch produces hundreds of different watch models at relatively low costs by assembling the variants from different combinations of standard chunks (Ulrich/Eppinger 2000, p. 187). However, modular product architectures can trigger some serious problems. Piller (1998, p. 197) cites five potential dangers of modularization. The development of modular product systems is costly and expensive compared to integral systems. Furthermore, complexity costs can be effectively reduced if it is possible to offer a high number of individual products using only few modules. Modular product architecture also involves that not all customer needs can be fulfilled because the variation occurs within certain combinations which are determined in advance. Further dangers of modularization are due to the relative easiness of imitation of modular designs from competitors and the risk of ignorance of innovation possibilities when the mass customizer continues to use standard modules. Efficient and well conceived modular product architecture enables to avoid these problems and to benefit only from its advantages.

2.2 Some Basic Approaches Related to Variety Management

In order to maintain costs at a low level, it is necessary to transform the problem of individual products into a mass production problem through an adequate reorganization of the product structure and the manufacturing process. In mass customization, customers should perceive the product as a tailor-made solution, while the product in reality is obtained by using more or less mass produced components and modules. After receiving customer order, the customizing process can be carried out on the basis of stock or pre-manufactured parts. Thus, the production process presents a Customer Order Decoupling Point (CODP), where the customizing process begins (Guoning 2003, p.1).



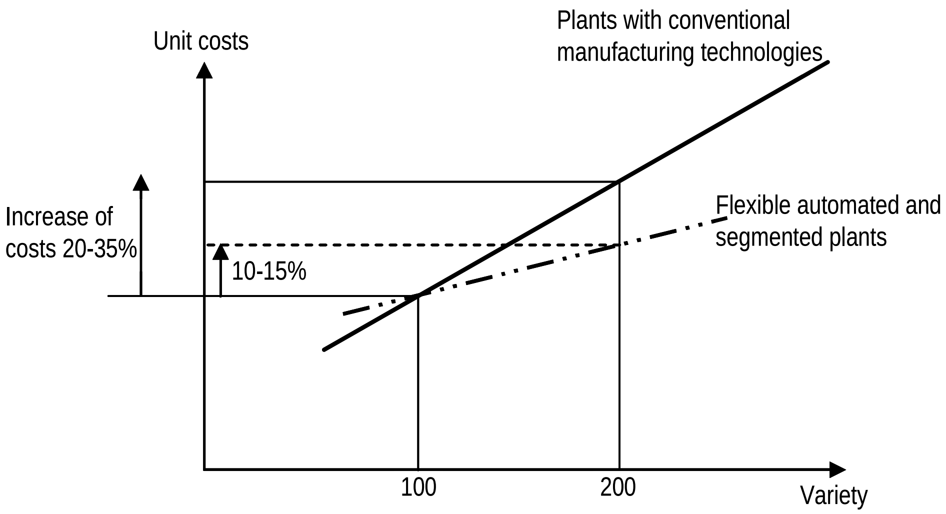
Source: Guoning 2003, p.1

Figure 1: The principal of the Customer Order Decoupling Point

Stable and flexible processes are also required for the manufacturing of customized goods and services. Development, purchase and sales of products are replaced by achievement potentials which are ex post transferred to a customer-specific problem solution. The production of customized products presupposes a direct interaction between customers and producer. Customers provide the producer with the necessary information related to the required product features (Rogoll/Piller 2002, p. 11). In this context, product configuration plays a decisive role. Configuration is an activity which enables to design a product on the basis of a set of component types and attributes by simultaneously satisfying a set of pre-defined design constraints (Felfernig et al. 2003, p. 49).

Thus, mass customization is based on a limited flexibility because product individualization occurs only at specific components within already defined dimensions or adaptation steps. Furthermore, on the one hand the offered variety has to satisfy the needs of all relevant customers and on the other hand the components being not decisive for individualization should be standardized (Rogoll/Piller 2002, p. 17).

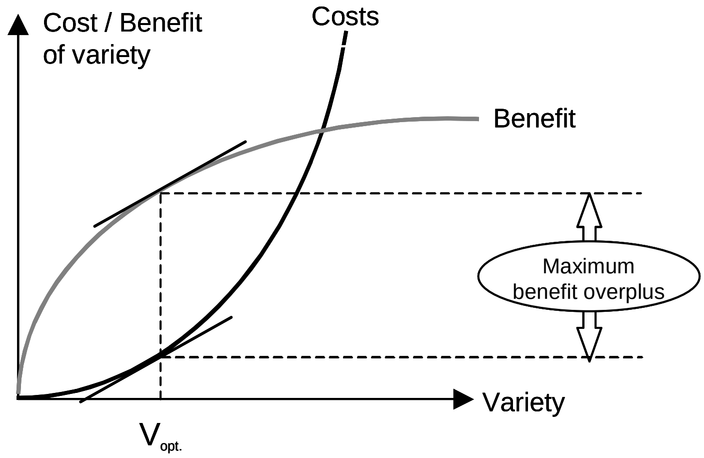
The proliferation of product variety is generally associated with additional costs due to increasing complexity. An empirical study carried out by Wildemann (1995a, p. 13) has shown that with higher variety, the inverted effect of the learning curve can be observed. For plants with conventional manufacturing technologies, with every doubling of variant numbers, unit costs increase about 20-35%. However, by means of flexible automation and shop floor reorganization and segmentation, costs increase about 10-15%.



Source: Wildemann 1995a, p. 14

Figure 2: The inverted learning curve with variety doubling

The principal goal of an efficient variety management is to find an optimal product variety which corresponds to the optimum of the cost-benefit equation. Figure 3 depicts that high product variety is not usually profitable because the cost curve exponentially increases compared to the benefit curve (Rathnow 1993, pp. 43). Nevertheless, this description has only a theoretical importance because in practice an accurate determination of variety benefit and variety costs, which include not only monetary but also non-monetary costs, is a very complex task.

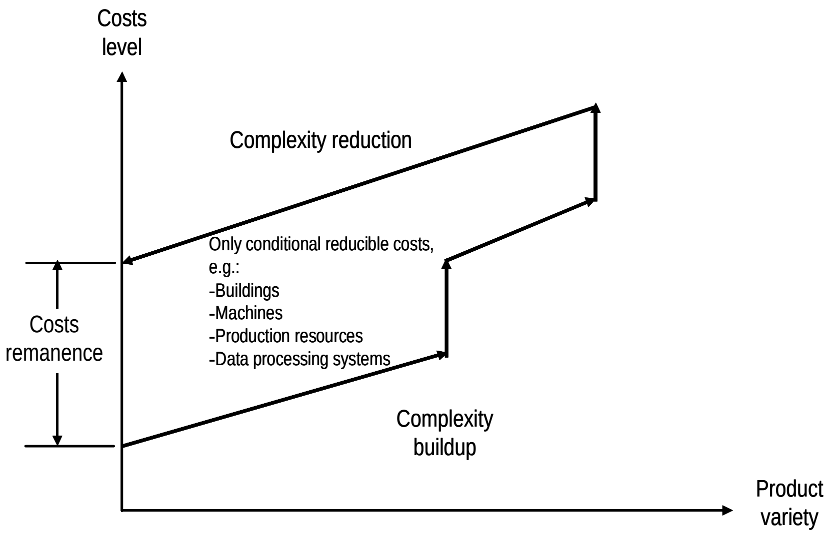


Source: Rathnow 1993, p. 43

Figure 3: Description of the optimum problem of variety

Anderson (1997, p. 45) defines two categories of external variety. The first category is useful variety, which is appreciated by customers and contributes to their satisfaction. The second category is useless variety, which is transparent, unimportant and causes bad effects such as customer confusion. In order to approach the variety optimum ($V_{opt.}$), useless variety should be eliminated. A simple tool such as ABC-analysis can be applied to support decision-making. For example, Nissan automobile had 87 steering wheels available. Seventeen types had been installed in 95 percent of Nissan cars, while 70 types in only 5% of the manufactured cars. In general, the benefit of such a variety does not compensate the additional costs due to complexity.

However, the effects of variety are not usually reversible. Increasing product variety generally necessitates the creation of additional structures and investments such as flexible equipments or expensive electronic data processing systems, which are fix costs. A rationalization of the product assortment by reducing the number of variants can make these investments or some of them superfluous. These costs can not be reduced in the short run and their effects are generally irreversible. This observed phenomenon having a similar effect to the hysteresis effect (see figure 4), is called costs' remanence (Caesar 1991, p.14, Loesch 2001, p. 46).



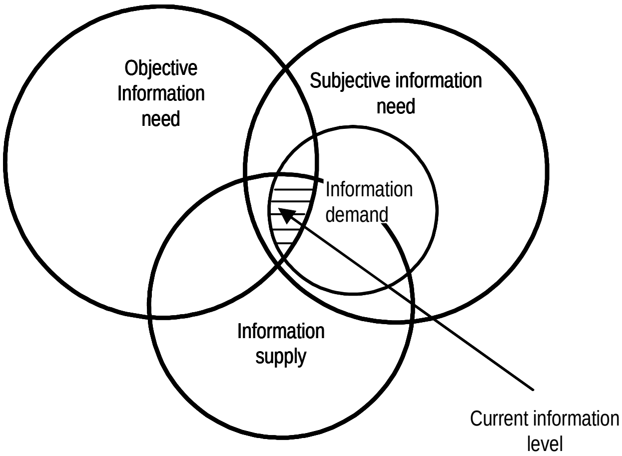
Source: Hichert 1986, p. 674

Figure 4: Costs remanence by reducing variety

A comprehensive concept for variety steering in mass customization should not only be restricted to considerations related to the optimization of internal complexity and variety. The concept also has to take into account the customer needs related to end product variants. In the following section, we introduce a model illustrating that wide variety in mass customization does not necessarily mean that every customer finds the product he really wants. This is due to the discrepancies existing between offered variety, objective and subjective customer needs.

2.3 Discrepancies between Offered Variety, Objective and Subjective Customer Needs

The explanation of the discrepancies between offered variety, objective and subjective customer needs will be based on a well-known model from the information theory, namely the information need and supply model. This model is described by figure 5. The objective information need defines which type and quantity of information a decision maker should use to fulfill a certain task. The subjective information need deviates from the objective one and indicates which information the decision maker considers as relevant for completing this task. Information demand presents again only a portion of the subjective information need. The current information level is the area where objective information need, information supply and information need overlap. This area corresponds to the supplied information, which actually serves to the task completion (Wigand et al. 1997, p. 88).



Source: Wigand et al. 1997, p. 89

Figure 5: Information need and information supply

Adapting the model of information need and supply to the variety problem makes sense because the development of products and variants principally reposes on information stemming from customers. In addition to the three circles representing the objective customer need, the offered variety and the subjective customer need the adapted model for variety contains a fourth circle representing the offered variety of the competitors.

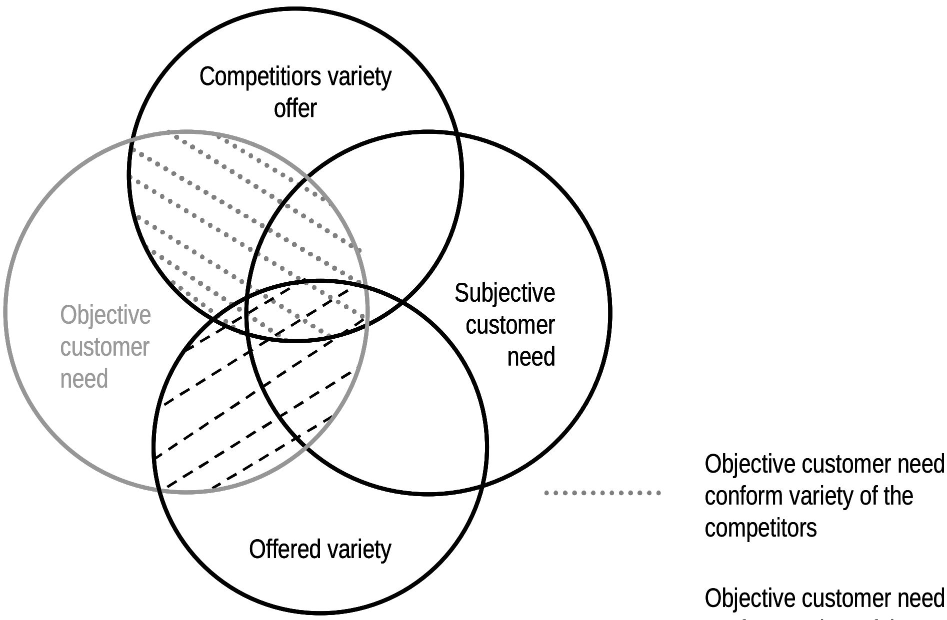


Figure 6: Adapted model for variety in a mass customization system

We define the subjective customer needs as the individually realized and articulated requirements, whereas the objective needs as the real ones perceived by a fictive neutral perspective. The existing discrepancies between the objective customer needs, the subjective customer needs and the offered variety are due to the following reasons:

- The customers do not know their real needs.
- The customers cannot correctly express their real needs.
- The mass customizer wrongly interprets customer requirements.

The model shows that in order to optimize variety, the mass customizer has to orient development and rationalization efforts toward the objective customer needs and in no way toward the subjective needs. The subjective needs lead to variants, which confuse the customers and present only suboptimal customer satisfaction. They may also cause higher complexity costs rather than benefits for the mass customizer. However, the subjective need is the expressed one and is relatively easy to detect by means of several methods such as customer interviews or conjoint-analysis. Jugel (2003, p. 414) confirms the deficiencies of these methods and points out that a customer needs analysis often results in customers actually preferring another product other than what they themselves believe. Ulrich and Eppinger propose a method enabling to help avoid, in part, the communication problems that can arise when customers express themselves. “Watching customers use an existing product or perform a task for which a new product is intended can reveal important details about customer needs” (Ulrich/Eppinger 2000, p. 63). The challenge for the company consists in being able to draw the boundaries of each type of need and to determine which variants are over engineered, which ones are corresponding to the subjective needs and which ones are fulfilling the objective needs of the customer.

The circle representing the variety offer of competitors puts an additional constraint when optimizing variety. Before adding new variants to the production program it is important to verify, whether these variants are in fact corresponding to the objective customer needs and whether they have not already existed in the production program of the competitors. The cost position has to be compared to that of the competitors.

The model of figure 6 suggests that there are two directions the mass customizer has to consider in order to achieve higher customer satisfaction. The first direction is to develop and offer product variants capable of satisfying the customer objective needs. The second direction is to help customers better know their objective needs.

3 Complexity Key Metrics in Mass Customization

3.1 Relevant Sub-processes in Mass Customization

As previously mentioned, the achievement potential of the mass customizer should cover all requirements of relevant customers. Therefore, the product configuration sub-process is considered as the main external driver of variety as well as complexity. Purchasing, production, development and logistic are the internal sub-processes generating variety inside the mass customization system. Furthermore, all these sub-processes can be influenced by the resulting variety. The information sub-process is a cross-section process ensuring a smooth information flow between all other sub-processes (Figure 7).

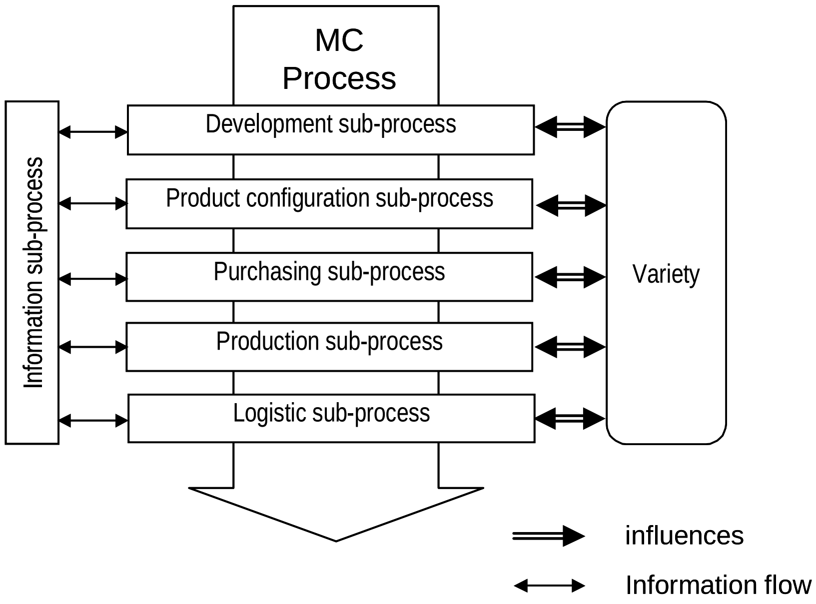


Figure 7: Relevant sub-processes in a mass customization system

The decision on the extension of the production program with an additional variant could increase variety in different company fields. For example, it is conceivable that the new variant requests the modification of some parts, the development or supply of new parts, which increases part numbers and variety inside the company (Zich 1996, p. 10, Battenfeld 2001, pp. 138). For example, the contribution of the production in increasing internal variety consists of using additional tool kits (Zich 1996, p. 11).

- Development Sub-Process

Providing high product individuality by maintaining a competitive cost position is a great challenge for mass customizers. During the development phase, 80 percent of the lifetime cumulative cost of a product is determined. For mass customization, product architecture determines 60 percent of a product's cost and presents therefore a high leverage opportunity for reducing costs (Anderson 1997, pp. 131). Moreover, product architecture is a development decision having a great impact to efficiently cope with variety (Ulrich/Eppinger 2000, p. 186).

Product architecture is either modular or integral. Modular architecture describes a low number of functions per component, whereas integral architecture presents a higher integration of functions per component. Integral product architecture triggers high complexity costs during the product life cycle (Ishii 1998, p. 3). Ulrich (2000, p. 186) points out that modular chunks allow changes to be made to a few isolated functional elements of the product without necessarily affecting the design of other chunks. Changing an integral chunk affects functional elements and requires changes to other related chunks.

The ideal product architecture for mass customization should enable to manufacture a high number of product variants on the basis of a high commonality of parts and components. The product platform concept plays here a decisive role and presents an efficient means to reduce complexity. A product platform is generally understood as a set of parts or components, which establish a common structure for many products. However, a platform strategy does not concern only the shared components at the product level. Manufacturing processes and techniques as well as knowledge of the personnel also pertain to the platform concept (Piller/Waringer 1999, pp. 64, Ulrich 2000, p. 200, Siddique/Rosen 2001, p. 1).

- Product Configuration Sub-Process

The interaction between producer and customers plays a decisive role in mass customization. An intensive communication process is necessary, in order to get from the customer the relevant information, which is important for the configuration and manufacturing of individual products (Piller 2000, pp.195). The customer is integrated in the value creation and is considered as a “co-producer” or “prosumer” (Toffler 1980, p. 274, Piller 2000, p. 196). The extent of this integration may vary from the simple configuration from predefined modules and components to real co-design of products (Piller/Moeslein 2003, p. 10).

The configuration activity is supported by trade or sales and distribution, for example, when the inquiry of individual information requires special devices, equipment or even knowledge. The configuration process can also be carried out by the customers themselves. In this case, a software tool is needed to make the self-configuration possible. A well-designed user interface should enable new customers being unfamiliar with the product to carry out the configuration without enormous efforts (Rogoll/Piller 2002, pp. 25).

The web-based configuration is a critical part of the mass customization service process and influences the overall quality perception. Customer satisfaction level depends not only on the end product quality but also on the web-based configuration process and interface. A lack of transparency during the configuration process can confuse customers and lead to process abortion (Riemer/Totz 2001, p. 5).

- Purchasing Sub-Process

The consequences of the generated variety during the development phase are also to observe at the purchasing level. The main complexity driving factors are parts and material variety, supplier variety, interfaces variety and quality variety. In order to optimize the purchasing processes, it is advantageous, for example, to carry out an ABC-analysis regarding purchasing volumes of the different material groups. Purchasing processes related to A-materials should be carefully examined. For B and C material groups the mass customizer can opt for a few typical processes having a relatively low complexity level (Wildemann 2000, p. 33).

An efficient means aiming at increasing efficiency of purchasing in mass customization is to reduce the number of suppliers. Dealing with a huge number of suppliers triggers higher complexity, hinders cooperative relationships and negatively affects quality. Concepts such as single sourcing where the company retains over a long period of time only one supplier for a specific part or family of parts, present a remedy for this problem and contribute to the realization of enormous advantages at cost, quality and delivery time levels (Maskell 1991, p. 210, Wildemann 1997, pp. 87).

The external purchasing of modules respectively systems is described as modular respectively system sourcing. These both concepts try to combine the two conflicting goals of lowering the vertical range of manufacture and reducing the number of suppliers. In a mass customization system the implementation of modular and/or system sourcing leads to a considerable reduction of purchasing complexity at the process and component levels (Wildemann 1997, p. 90, Wildemann 2000, p. 39).

- Production Sub-Process

The production process plays an important role in the success or failure in mass customization. In order to be able to offer a high product variety while maintaining a competitive customer service time, the manufacturing system should be flexible (Kaluza 1989, pp. 287). Flexibility is guaranteed when the delays arising by switching over from one variant to another are considerably reduced, ideally to zero. These delays called set ups are non-value adding activities and trigger long manufacturing lead times (Anderson 1997, p. 177).

A relevant concept aiming at reducing complexity in production is to apply modularity on the shop floor. The resulting organization is a modular one based on manufacturing cells "where dissimilar machines are grouped together based upon the manufacturing process that is completed within the cell" (Maskell 1991, p. 157). Furthermore, modular organization reduces the number of linkages between machines and leads to short production lead times (Wildemann 2000, p. 47).

In addition to product commonality, the mass customizer also has to strive for a high production process commonality. This means that the different variants can be manufactured on the basis of few production processes. As a result, a certain level of stability as well as straightforwardness can be guaranteed (Maskell 1991, p. 157). Thus, production complexity and perturbation sensitivity of the processes are reduced (Wildemann 1997, p. 152). Honeywell's thermostat production facility in Golden Valley, Minnesota is a good example illustrating the importance of flexible manufacturing to increase process commonality. This company originally had different production lines for each of its three products. By means of a flexible manufacturing system, all products are manufactured on a single line, while slashing product changeover time from 25 minutes to three minutes (Berman 2002, p. 56).

- Logistic Sub-Process

The design of the logistic system in mass customization can provide some additional individualization opportunities. For example, the customer may choose from many logistic options related to payment, packaging and transport. Real individualization is about two aspects: individual packaging (e.g. gift-wrapping and packages enclosing individual greetings) and individual delivery times. Especially the last aspect has a real advantage for customers by respecting their individual time schedules (Riemer/Totz 2001, p. 6).

The mass customization system does not generate inventories at the end product level because the individualized products are not manufactured until a customer order arrives. Yet, work-in-process inventories of mass produced modules and standard components as well as raw materials for individualized processing can exist (Piller 2002, p. 6). To check out, whether the logistic system of a mass customizer is smoothly working, it is important to keep the work-in-process inventory in view. “Most things that go wrong in a logistics system cause inventory to increase” (Tersine/Wacker 2000, p. 114).

The Just-in-Time layout consisting of grouping different machine types in manufacturing cells improves the material flow and reduces considerably transport times on the shop floor. This leads to an increasing flexibility as well as to a decreasing work-in-process inventory (Wildemann 1995a, pp. 112).

Furthermore, mass customization needs a highly coordinated supply chain. The main goal is to provide the right good to the right customer at the right time. With virtual integration, the company pursuing the mass customization strategy seeks to maintain close relationships with partners, which are more capable of performing specific functions (Berman 2002, p. 56). The advantage of such integration is to benefit from partner specialization, to extend the individualization level, to increase flexibility with low costs and to reduce complexity (Rogoll/Piller 2002, pp. 24).

- Information Sub-Process

For a company using mass customization it is impossible to exactly know before receiving an order what parts are needed, what goods are to be produced and what goods are to be shipped. Moreover, with the increasing number of product variants the information process complexity exponentially increases. An efficiently integrated information system in mass customization should capture customer product configuration (e.g. over the web), develop a list of product requirements from suppliers necessary to achieve the order, determine specifications of manufacturing in regard to the customer configuration, set up the manufacturing system, arrange for end product shipment and enable to verify a product’s order status (Berman 2002, pp. 57).

In mass customization, the information systems should enable the supply chain to operate as an integrated unit. The integration of the different information systems is of critical importance in order to guarantee that the whole system effectively runs. For example when an unexpected change arises, the suppliers can immediately react and adjust their activities. This leads to an increasing flexibility which is required in mass customization (Oleson 1998, p. 91).

3.2 Complexity Key Metrics

Key metrics are defined as quantitative measurements that give utile information related to measurable facts through aggregation and relativization. They are generally used in operational controlling and their application serves for control and steering of success potentials (Reichmann 2001, pp. 19). Key metrics have different functions and can be either used as information or steering instruments. Key metrics such as those delivered by annual accounts serve for information purposes, to describe the development of the company in the past and to appreciate business trends. Steering key metrics are used in connection with predefined goals and indicate to what extent these goals are achieved (Kuepper 2001, pp. 344).

Using the described sub-process model, the key metrics considered to be important for detecting variety-driven complexity in mass customization will be presented. In order to guarantee a certain computation ease of the key metrics, those which are related to costs are not considered. Calculating accurate complexity costs in a complicated system such as mass customization is often associated with enormous expenses. For example, the application of Activity-Based Costing (ABC) to compute complexity costs, not usually leads to good results. Furthermore, this method is simultaneously associated with high implementation costs (Schaefer 1993, pp. 311, Eberle 2000, p. 346). Other measurements related to e.g. time that can be already available in the company are significant and generally do not require additional efforts.

- Complexity Key Metrics for the Development Sub-Process

During the development process, engineers have to consider already devised and used parts. The main goal is to use each part in as many products as possible because "*products that use many common parts inherently have less variety cost than products with unique parts*" (Anderson 1997, p. 78). The conception of new products on the basis of standardized and common parts leads to the reduction of complexity at the development stage. The use of unique parts has to be kept at a low level, ideally at zero (Maskell 1991, p. 178, Anderson 1997, p. 92).

Martin and Ishii (1997, p. 3) defined the commonality index (CI) indicating to what extent the different product variants within a product family are based on fewer unique parts.

[1] $$CI = 1 - \frac{u - \max p_j}{\sum_{j=1}^{v_n} p_j - \max p_j};$$

$0 < CI \leq 1$
u : number of unique part numbers
p_j : number of part numbers in model j
v_n : final number of varieties offered

Source: Martin/Ishii 1997, p. 3

As previously explained, a mass customizer has to reduce internal variety and complexity by means of modular product architecture. “The best method for achieving mass customization…is by creating modular components that can be configured into a wide variety of end products…” (Pine 1993, p. 196). Without modularity, it is difficult, even impossible to pursue a successful mass customization. That is why, we consider that in mass customization the components assembled into end products are modules. If product variants are manufactured from a finite number of modules leading to u=0, then CI>1 what is totally absurd. Subsequently, the key metric CI may be suitable when products have an integral architecture but not when they have modular or building bloc architecture. Moreover, Martin/Ishii (1997) do not explain, how to determine the unique parts in the product family. Maskell (1991, p. 179) points out that the method to be used to distinguish between common and unique parts can be different from one company to another and that there is not only one suitable method. Parts which are used in few product variants have to be considered as non-common parts. Furthermore, a component built in a large number of end product variants, but presenting a very little percentage of the company output has to be considered as a non-common component.

The combination of both common part and module strategies leads to the common modules strategy (Nilles 2002, p. 140). Therefore, we define a key metric capable of tracking modules commonality. However, a high modules commonality should not be associated with low commonality of the parts to be assembled into modules. It is obvious that modules can reduce complexity but the modules complexity itself should be kept at a low level. Therefore, it is relevant to introduce another key metric detecting the commonality level related to the parts of the modules. However, the modules being directly delivered from suppliers within the scope of modular sourcing should not be considered for the computation of the parts commonality. Thus, only the modules which are assembled inside the company and requires further parts should be considered.

In order to determine the common modules and parts, Anderson (1997, pp. 103) proposes to consider their usage level to determine the "high runners" and the "low runners". This analysis is completed by a further analysis checking out which parts or modules are used in most products. This method is also suitable for rationalizing the modules and parts lists. Both key metrics, namely modules commonality metric and parts commonality metric can be used to track the commonality level of components in mass customization.

[2] $$\text{Modules commonality metric (MCM)} = \frac{\text{Number of common modules}}{\text{Number of all modules}}$$

[3] $$\text{Parts commonality metric (PCM)} = \frac{\text{Number of common parts}}{\text{Number of all parts}}$$

However, the problem is still consisting in how to determine the common modules and parts. We propose an algorithm taking into account both criteria of Anderson, namely usage level and number of products using the module or the part. The algorithm is proposed for modules. To compute the number of common parts, the algorithm can be easily adapted.

- For each module M_i determine the product variants P_j which have already used the module M_i
- For each module M_i determine the number of modules n_{ij} assembled in P_j
- For each module M_i determine the sales in unit S_j of P_j
- For each module M_i compute the term L_i (Weight of the module M_i) where

[4] $$Li = \frac{\sum_{j=1}^{k_i} n_{ij}\, S_j\, P_j}{\sum_{i=1}^{m}\sum_{j=1}^{k_i} n_{ij}\, S_j\, P_j};\quad \begin{array}{l} m: \text{number of all modules} \\ k_i: \text{number of products using the module } M_i \end{array}$$

- Compute the mean value of L_i

[5] $$\text{Mean value} = \frac{1}{m}\sum_{i=1}^{m} L_i$$

- For each M_i compute (L_i – Mean Value)
  When (L_i – Mean Value)≥ 0 then M_i is a common module
  When (L_i – Mean Value)<0 then M_i is not a common module

In order to improve the commonality way of thinking in product development, it is relevant to create a common basis for many derivative products and models by developing a product platform. Nilles (2002, p. 136) defines a product platform as a spatially locked functional unit which has unambiguously defined interfaces. He also points out that a product platform should be considered as a standardized part of the product system structure.

Meyer et al. (1997, p. 10) introduce the platform efficiency metric and point out that platform efficiency increases when the follow-on products can be rapidly created without enormous efforts and costs. Subsequently, the complexity of the development process considerably decreases because different product variants can be easily and efficiently derived.

[6] $$\text{Platform efficiency metric (PEM)} = \frac{\text{R \& D time for derivative product}}{\text{R \& D time for Platform version}}$$

Source: Meyer et al. 1997, p. 10

A relevant metric for mass customization showing the variant flexibility is the multiple use metric (E_v) of Ericsson and Erixon (1999, p. 127). It is the quotient of the number of product variants and the total number of required modules. A high value of this metric indicates that the whole range of product variants can be produced on the basis of few modules For example, the panel meter of Nippondenso can be assembled into 288 variants out of 16 total modules and has an E_v of 18.

[7] $$E_v = \frac{N_v}{N_{mt}};$$

E_v : multiple use metric
N_v : number of product variants required by customers
N_{mt} : total number of modules required to build up all the product variants

Source: Ericsson/Erixon 1999, p. 127

The main advantage of modular product architectures is to generate a wide range of variety by mixing-and-matching few modules according to customer specifications. The complexity of a modular architecture is how to efficiently specify and standardize the interfaces between the different modules (Mikkola 2001, pp. 3). The advantage of a low interface complexity is to enable a parallel product development in order to decrease development lead times (Ericsson/Erixon 1999, pp. 17, Wildemann 2003, p. 157). The interface complexity metric is defined as follows:

[8] $$I_c = \frac{\sum_{i=1}^{N_m - 1} T_i}{A_t};$$

I_c : interface complexity metric
N_m : number of modules in one product variant
T_i : assembly time for one interface
A_t : ideal assembly operation time

Source: Ericsson/Erixon 1999, p. 114

- Complexity Key Metrics for the Configuration Sub-Process

Mass customization is not necessarily connected to electronic business, but its growth is essentially due to the development of the internet economy (Franke/Piller 2002, p. 7). In this section, we consider that customers have the possibility to carry out the product configuration over a toolkit for mass customization called configuration system or configurator which is integrated within the website. The utilization of configuration systems enables the mass customizer to gain valuable information about customers and website visitors.

Piller and Tseng (2003, p. 520) cite the example of Cmax.com sport shoes and point out that the entire surface of the earth would scarcely suffice for exhibiting all the possible variants. A shop having a size of 7,000 times the surface of the earth would be needed for all variants. Variety is in fact important to fulfill all the needs of customers but it is not usually obvious, whether a very large product assortment is actually required and honored by customers. The mass customizer should offer the optimal variety, which maximizes customer satisfaction while keeping low costs and especially those due to complexity. The key metric referring to the used variety captures the perceived variety rate compared to the theoretically possible product variants. Low values of this metric indicate that many variants may not be perceived or may be uninteresting for customers.

[9] $$\text{Used variety metric (UVM)} = \frac{\text{Number of perceived variants}}{\text{Number of all possible variants}} \qquad 0 < \text{UVM} \leq 1$$

Source: Piller 2002, p. 15

Consumers are confused and usually experience complexity when they have to choose between numerous options (Huffman/Kahn 1998, p. 493). Huffman / Kahn define two types of complexity which are perceived and actual complexities. These two types are independent from each other because a higher actual variety does not necessarily improve the perceived variety. In this context, the information presentation format plays a decisive role for facilitating information absorption and decreasing uncertainty during the buying process. When customers feel overloaded with information which can exceed their information processing capacity, they would not complete and abort the configuration process (Huffman/Kahn 1998, p. 493, Piller/Tseng 2003, p. 519).

In addition to the used variety, we assume that both parameters referring to the time required to entirely fulfill one configuration and the configuration abortion rate are very important to capture the perceived complexity level. According to Piller (2000, p. 279) the configuration process should be performed in few minutes, in few hours when the product is considerably complex, but in no way in several weeks. Consequently, a high configuration abortion rate and a long configuration time would suggest that the presentation format is not suitable for displaying product variety. Furthermore, It may be useful to distinguish between old and new customers when analyzing the configuration time because old customers may take less time for product configuration than new ones.

[10]
$$\text{Average configuration length of time (CT)} = \frac{\sum_{i=1}^{N} CT_i}{N}$$

CT_i : time needed from one customer to fulfil one configuration

N : number of fulfilled configurations

[11]
$$\text{Configuration abortion rate (AR)} = \frac{\text{Number of aborted configuration processes}}{\text{Number of log-ins}}$$

- Complexity Key Metrics for the Purchasing Sub-Process

As previously mentioned, the mass customizer can reduce complexity of the purchasing process by applying concepts such as process standardization and modular sourcing. Standardization efforts at the product itself generally lead to the reduction of the number of unusual parts. Anderson (1997, pp. 93) points out that it is advantageous to examine, whether it is possible to replace the part having the optimal size with the part having the next larger standard size. Although this is associated with higher direct costs, cost advantages which result from savings at the overhead costs may be larger. Moreover, the procurement of unusual parts is costly and slow. Thus, the key metrics that have to be defined should take into account all these aspects, namely modular sourcing, standardization of both purchasing processes and used parts.

[12]
$$\begin{array}{l}\text{Percentage of module suppliers} \\ \text{in comparison to the number of all suppliers (MS)} = \frac{\text{Number of module suppliers}}{\text{Number of all suppliers}} \times 100\end{array}$$

[13] $$\text{Purchasing process commonality metric (within a part category) (PPC)} = \frac{\text{Number of standardized purchasing processes}}{\text{Number of all purchasing processes}}$$

[14] $$\text{Percentage of standardized parts (within a part category) (SP)} = \frac{\text{Number of standardized parts}}{\text{Number of all parts}} \times 100$$

- Key Metrics for Variety Steering in the Production Sub-Process

The ability to have acceptable delivery times in mass customization is a great challenge. Before the customer order arrives, it is impossible to predict which individualized variants have to be supplied. However, mass produced components and subassemblies can be manufactured and stored independently from the customer order. Therefore, the goal is to displace the variant determination point towards the end of the value chain in order to avoid variety proliferation at the begin of the process. So it is possible to optimize inventory costs while offering a high delivery service (Roever 1991, p. 264, Wildemann 1995b, pp. 190, Waller et al. 2000, p. 134).

Martin and Ishii (1996, p. 6) define the Differentiation Point Index (DI) capturing the position where the product differentiation occurs within the process flow. The denominator of this index shows the worst case where all variants are determined at the beginning of the production process and the numerator reflects to what extent the actual process flow moved away from the worst-case situation. The lower the value of DI the better.

[15] $$DI = \frac{\sum_{i=1}^{n} d_i\, v_i\, a_i}{n\, d_1\, v_n \sum_{i=1}^{n} a_i} \quad ;$$

v_i : number of different products exciting process i
n : number of processes
v_n : final number of varities offered
d_i : average throughput time from process i to sale
d_1 : average throughput time from beginning of production to sale
a_i : value added at process i

Source: Martin/Ishii 1996, p. 6

We agree that this index is suitable and even important for a mass customization system. It incorporates all parameters (lead times, value growth along the whole process and the number of variants) being according to Wildemann (2000, p. 47) crucial for the determination of the optimal differentiation point. A low index value means that the differentiation between variants occurs at a late point in the production process. When new variants that can be manufactured on the basis of the same production process are added to the production program, the variation of the index value should be examined. If the index remains constant or varies a little then the associated overhead costs essentially due to inventory costs will not significantly increase. If not, then it is necessary to examine, whether it is profitable to add these variants. Figure 8 shows two production processes having different differentiation indexes.

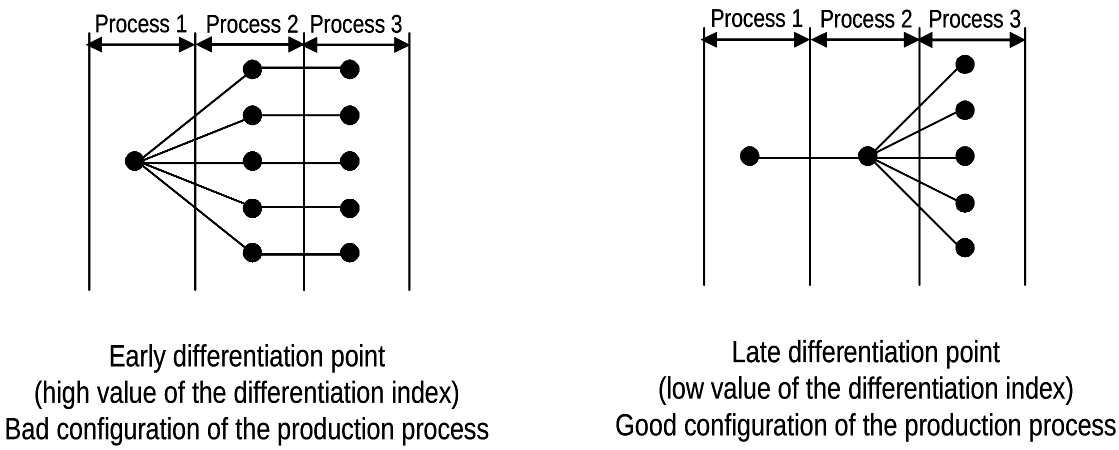


Figure 8: Early versus late differentiation point

Offering a large product variety is associated with high setup costs. Pine (1993, pp. 50) points out that when reducing setups and changeover times, the optimal batch size tends towards one. This is in accordance with the main goal of mass customization, namely, to offer products fitting individual requirements. Martin and Ishii (1996, p. 6) define the setup cost index (SI) which aggregates all setups for the product and normalizes it with the total costs of all products.

[16] $$SI = \frac{\sum_{i=1}^{n} v_i \, c_i}{\sum_{j=1}^{v_n} C_j}; \qquad 0 < SI < 1$$

v_i : number of different products exciting process *i*
n : number of processes
v_n : final number of varieties offered
c_i : cost of setup at process *i*
C_j : total cost (material, labour, and overhead) of j^{th} product

Source: Martin/Ishii 1996, p. 6

In mass customization the computation of overhead costs is difficult and complex. As previously explained, it is more efficient to use parameters, which are easy to compute and simultaneously correlating with costs. Therefore, we agree to adapt the setup cost index by considering lead times rather than costs. Furthermore, in opposition to cost considerations, lead times can show the process flexibility degree and to what extent it is possible to produce high product variety in very little batches.

[17] $$SM = \frac{\sum_{i=1}^{n} v_i \, t_i}{\sum_{j=1}^{v_n} T_j}; \quad 0 < SM < 1$$

v_i : number of different products exciting process *i*
n : number of processes
v_n : final number of varieties offered
t_i : average time needed for a setup at process *i*
T_j : average total lead time needed for the manfacturing of j[th] product

In order to determine the manufacturing lead time T_j Ericsson and Erixon (1999, pp. 36) define the key metric referring to the number of modules in a product. It is supposed that the assembly of each module occurs concurrently with the others. Then all modules are delivered to the main assembly line, where they are entirely assembled into a complete product. The total lead time value L is the sum of the time needed for parts assembly into modules, the time for functional testing of modules and the time for modules assembly into the end product.

[18] $$L = \frac{N_p \, T_a}{N_m} + T_t + \frac{N_m - 1}{T_i};$$

L : lead time
N_p : number of parts in a complete product
N_m : number of modules in one average product variant
T_a : average assembly time for one part
T_t : average time for functional testing of modules
T_i : average assembly time for interfaces between modules

Source: Ericsson/Erixon 1999, p. 118

This metric *L* does not take into account the modules delivered by suppliers that do not require to be assembled in the plant. Furthermore, L considers only one non-value adding activity during manufacturing, namely, functional testing of modules. However, on the shop floor many other non value-adding activities arise such as move and wait times. The adapted key metric T_j for a product *j* considering all non-value adding activities, is defined as follows:

[19] $$T_j = \frac{N_p \, T_a}{N_m} + T_{nva} + \frac{(N_m + N_S) - 1}{T_i}$$

T_j : lead time for the manufacturing of product j
N_p : number of all parts assembled in modules in the plant
N_m : number of manufactured modules in one average product variant
N_S : number of supplied modules in one average product variant
T_a : average assembly time for one part
T_{nva} : average time for non value adding activities
T_i : average assembly time for interfaces between modules

[20] $T_{nva} = \text{move time} + \text{wait time} + \text{inspection time} + \text{setup time}$

Source: Maskell 1991, p. 258

Another parameter which is important to be evaluated in a mass customization system is the capacity utilization. Hildebrand/Mertens (1992, p. 71) define the capacity utilization as the ratio of the output to the actually available capacity. Mueller (2001, p. 73) defines a hierarchical system for capacity controlling and points out that the evaluation of capacity utilization has to be based on two main parameters namely processing and idle times. Mueller's definition is more precise than Hildebrand/Mertens' definition and will be therefore adopted in this paper.

[21] $\text{Capacity utilization metric (CUM)} = \frac{\text{Processing time}}{\text{Processing time} + \text{idel time}}$

Source: Mueller 2001, p. 73

Due to the great number of possible variants, it is of extreme relevance to ensure the flexibility of the production processes. The large variety should be manufactured on the basis of few production processes. There are two relevant report levels. The first report refers to the total number of different available processes within the plant and the second shows the commonality of these processes across the products (Maskell 1991, p. 181). The introduction of new product variants may modify the process commonality level. A lower commonality will trigger higher complexity and lower flexibility. That is why it is necessary to define a key metric referring to the production process commonality.

[22] $\text{Production process commonality metric (PPCM)} = \frac{\text{Number of common production processes}}{\text{Number of all production processes}}$

- Complexity Key Metrics for the Logistic Sub-Process

As aforesaid, a mass customizer has to carefully track the evolution of the work-in-process inventory. High inventory dramatically reduces the efficiency of the logistic process and is considered as process waste. A suitable key metric enabling to evaluate the process efficiency is the work-in-process turnover, which is defined as the ratio of total sales to the value of the work-in-process inventory (Pine 1993, p. 112). When the mass customizer introduces new variants, it is relevant to evaluate how the value of this key metric changes. A lower turnover due to higher variety triggers an increase of inventory costs and also complexity costs.

[23] $$\text{Work-in-process turnover (WIP)} = \frac{\text{Total sales}}{\text{Value of the work-in-process inventory}}$$

Source: Pine 1993, p. 112

Furthermore, it is crucial to deliver the right product at the right point in time. Sometimes the individualization occurs on the level of delivery times. Moreover, providing a large variety requires a highly coordinated supply chain. Delivering at time means that the complete system including partners, suppliers and all steps of the value chain efficiently work together. For this reason it is relevant to keep track of the key metric called delivery time reliability.

[24] $$\text{Delivery time reliability (DR)} = \frac{\text{Agreed delivery time}}{\text{Real delivery time}}$$

- Complexity Key Metrics for the Information Sub-Process

The product configuration system is the interface between the customer and the mass customizer and enables the exchange of information. Changes in the production program lead to the addition or elimination of variants and also components or modules. That is why, the configuration system must be updated as fast as possible in order to avoid such situations where the customer orders a product variant that is no longer available in the product assortment. The changes may also affect the configuration logic leading to modifications in the way the components or modules interact with each other. Moreover, the integration level of the configuration system in the existing business processes plays a decisive role and enables a certain automation degree of the order processing in mass customization. Furthermore, some changes on the configuration system level can be automated without a manual intervention (Rogoll/Piller 2002, pp. 38). Therefore, we define the following key metrics:

[25] $$IL = \frac{NIP}{NP}$$

IL : Integration level of the product configuration system in the existing business processes
NIP : Number of business processes integrated in the configuration system
NP : Number of all business processes

[26] $$FIC(\Delta T) = \frac{NC(\Delta T)}{\Delta T}$$

$FIC(\Delta T)$: Frequency of introducing changes in the configuration system at a period ΔT
$NC(\Delta T)$: Number of changes and data base up dates at a period ΔT
ΔT : Period of time

[27] $$AT_c = \frac{\sum_{i=1}^{nc} T_{c_i}}{nc}$$

AT_c : Average time for carrying out one change in the product configuration system

T_{c_i} : Time required for change i

nc : Total number of changes introduced in the configuration system

[28] $$AT_{(cc \to dp)} = \frac{\sum_{i=1}^{no} T_{(cc \to dp)_i}}{no}$$

$AT_{(cc \to dp)}$: Average time elapsed from configuration until documents preparation for manufacturing

$T_{(cc \to dp)_i}$: Time elapsed from the completion of configuration i until documents preparation

no : Number of all orders

The integration level of the product configuration system points out to what extent the configuration system is integrated in the existing business processes. This primarily depends on the number of integrated information systems and of the existing interfaces leading to breaks in the information flow. The frequency of changes and the time needed for achieving them are associated with considerable costs. When changes are frequent and costly, it may be better to change the configuration system or to increase its integration level. Such an investment decision is crucial for a mass customizer and must be supported by calculations comparing between several alternatives such as costs when keeping on working with the same configuration system and costs of new configuration system. The average time elapsed from configuration completion until final preparation of all documents which are necessary for manufacturing such as production routings and task schedules planning detects the speed of the information process in a mass customization system. For example, the analysis of this metric with respect to product variants shows which variants require the longest times for preparing their specific documents.

3.3 Preliminary Key Metrics aggregation model

The main goal of using sub-processes as a starting point for determining the key metrics for variety steering in mass customization was to guarantee a certain degree of completeness of the obtained key metrics. But the simple classification of these key metrics by sub-processes does not allow understanding how the different key metrics correlate with each other and which connections are existing between them. Therefore, we agree that it is advantageous to aggregate the key metrics in a comprehensive model where the interactions existing between them are obvious. By means of this model, it is possible to appreciate which aggregates will be influenced when a change occurs at the values of key metrics in other aggregates of the model.

In order to explain the transition from the sub-processes model to the aggregated model, we agree that the main sub-processes we have to start from are the development process, the configuration process and the information process. As previously mentioned, the mass customizer offers an achievement potential using a modules description of the product variants. This achievement potential is supported by a specific product architecture, which is conceived during the development process. The configuration individually occurs through the customer or with support of trades or sales. Here, the data format and the web site appearance are relevant in the presentation of the configuration system. Furthermore, the information process converts the individual product configuration into manufacturing specifications. Therefore, the integration level of the configuration system in the existing processes is of high relevance.

The starting 3 aggregates of the conceived key metrics model are: product architecture, web site appearance and data format and integration level and maintenance easiness of the configuration system. The web site appearance and data format have a direct influence on the used variety. The product architecture has also a direct connection to the used variety. This connection is evident because customers configurate their product variants on the basis of already conceived modules. As already explained product variants should be manufactured on the basis of common parts and modules as well as standardized components in order to decrease the complexity level. Engineers have to use components that are contained in as much product variants as possible. Moreover, we have shown that commonality also depends on the number of sold product variants. That is why, it is logic that components commonality is influenced by the aggregates referring to product architecture and used variety.

We distinguish between production process commonality and purchasing process commonality. A product architecture that is based on a product platform affects not only the components commonality but also the production process commonality for all models and product variants. Therefore, we can state that the product architecture has a direct influence on the production process commonality. The components commonality also has a relevant influence on the production process commonality. When parts present a high degree of commonality then the similarity of production processes is higher. Production process commonality has a direct effect on setups because common processes are flexible processes that generate lower setup times. Moreover, setup times influence the capacity utilization, which again affects the manufacturing cycle times.

Components commonality also influences commonality of processes at the purchasing level. Common purchasing processes positively affect manufacturing cycle times because common purchasing processes are simply processed and the supplied goods are delivered faster. Components commonality also leads to a simplification of the purchasing system and also to a greater participation of module suppliers which again influences the manufacturing cycle times. Manufacturing cycle times are also affected by the speed of preparation of the documents necessary for manufacturing and by the integration level of the configuration system in the existing information processes. Manufacturing cycle times affect the position of the differentiation point that again influences the work-in-process inventory as well as the delivery times reliability. A low differentiation point index means that the degree of completion is high and that the differentiation occurs at a late point in the production process. Figure 9 visualizes the connections existing between all the key metrics.

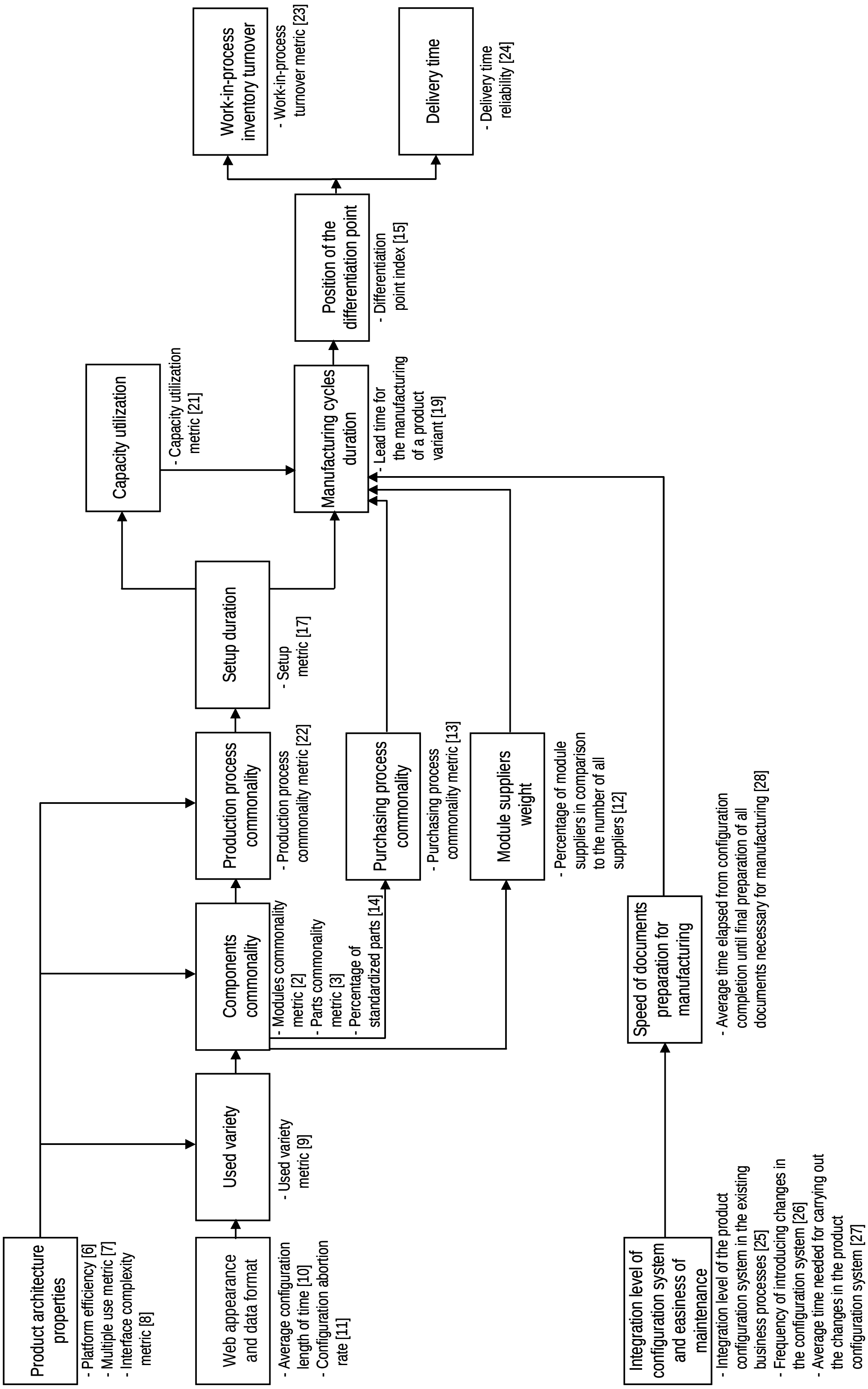
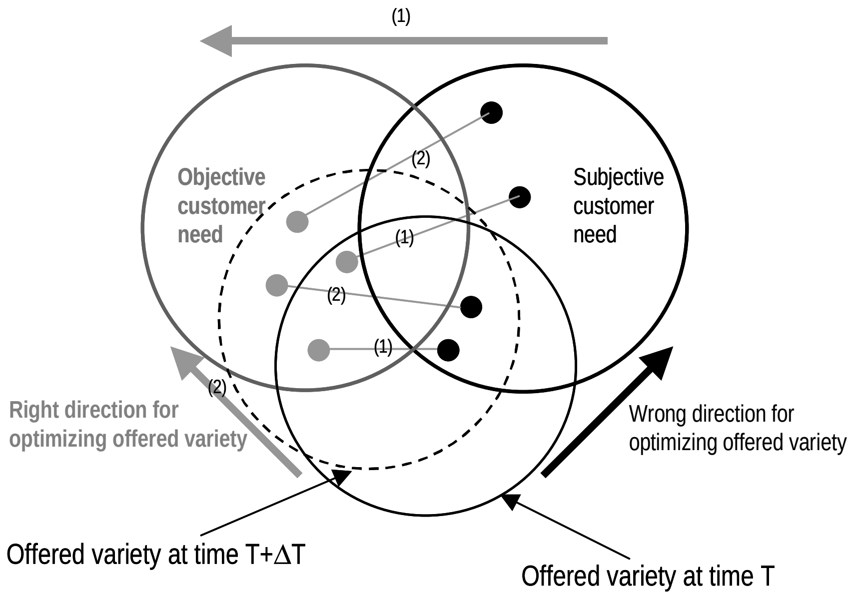


Figure 9: Preliminary key metrics model for mass customization

4 Modification of the Preliminary Key Metrics Model

There are two directions the mass customizer has to consider in order to fulfill the objective customer needs. The first direction is to try to help customers better get to know their objective needs by means of adequate configuration systems. This direction deals with how to help customers recognize their objective needs. This means that two different presentations of the offered variants supported by two differently conceived configuration tools can lead to different customer decisions. With the aid of an efficient presentation, customers may rather configurate the variant fulfilling their objective needs. However, the fulfillment of the objective needs is restricted by the extent of the offered variety. It is conceivable that in some cases, there is no variant among all variants in the product assortment that really fulfill the objective customer needs. That is why, the mass customizer has to consider a second direction enabling to optimize variety in regard to the objective needs. This will be attained by determining the variants to be introduced to the production program that contribute to increase the probability that customers find a variant fulfilling their objective needs. Over engineered variants as well as those which correspond solely to the subjective needs should be eliminated. Figure 10 shows how to optimize variants with regard to objective and subjective customer needs. In order to keep the figure clear the circle corresponding to the variants of competitors is not represented.

The preliminary key metrics model does not take into account the customer needs and should be therefore completed. The extension of the preliminary model with customer considerations will lead to the final key metrics model. In order to obtain the final model it is necessary to describe the existing methods and concepts that would solve the problems that arise when distinguishing between the objective and the subjective customer needs. In the following Kansei engineering as well as the key value attributes concept will be presented. Their contributions in solving some aspects of the objective and subjective needs' problem are also discussed. Then, we will describe the difficulties related to the identification of the objective needs. To perfect the final model, additional approaches from the consumer psychology field will be described.



- ● Variant corresponding to a subjective customer need
- ● Variant corresponding to an objective customer need

(1) Configuration system potential to make customer recognizing their objective needs within the scope of the offered variety

(2) Optimization of the offered variety in regard to the objective needs of the customers

Figure 10: Variety optimization with regard to subjective and objective customer needs

4.1 Kansei Engineering Concept

Kansei engineering is a consumer-oriented technology for new product development. It is defined as "translating technology of consumer's feeling and image for a product into design elements" (Nagamachi 1995, p. 2). The Kansei engineering system involves a computer-assisted system, an expert system and databases. In the Kansei word database, Kansei words which represent consumer's feelings on a product are stored. The image database makes up the relation between Kansei words and the design elements. Customers express their feelings on a product by entering personal and life style data. Then the system finds the best-fit designs, which are shown on the display of a computer (Nagamachi 1995, p. 6, Nagamachi 2002, pp. 290). Kansei words are organized into a space of independent axis, which can be obtained by using differential semantics. These axes are called semantic axes. The customer introduces the desired image in terms of punctuation in each of the semantic axis where he chooses a point in a scale of several points. The placement of one point on the semantic axis depends on the perceptions and feelings of each customer (Porcar et al. 2001, pp. 1). For example, the individual perception of watches can be represented by means of three dimensions (semantic axes): material and social representation, functional and logical representation, and aesthetic representation (Hsu et al. 2000, p. 376).

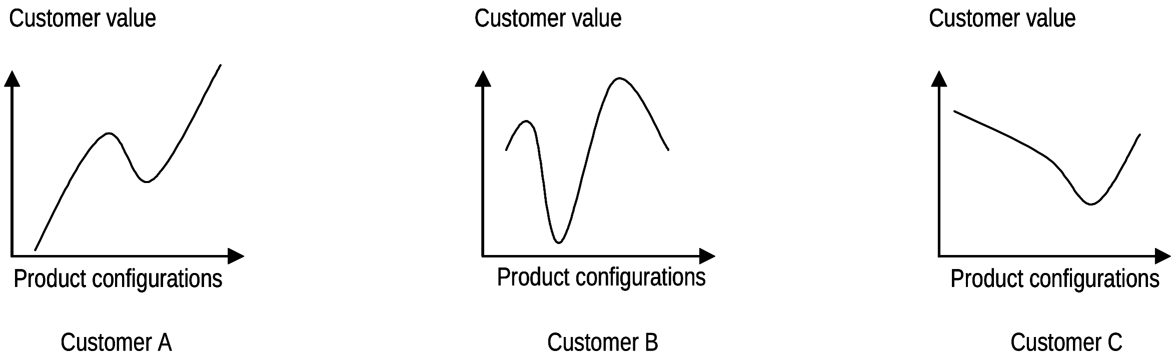
The objective customer needs are the real needs, which are implicit and hardly to express. Kansei engineering is a method which is based on feelings and perceptions. Therefore, we agree that via this technology it is possible to approach the objective customer needs. Moreover, with a module or part presentation customers has to construct on their own the end product by making decisions on several product parameters. This task is generally not easy and can be laborious for customers. “The majority of people are able to say if they like a product (or a service). They are capable of choosing between houses, watches or car insurance. But being able to construct each of those things merely adding parts is not so easy” (Porcar et al. 2001, p. 2). We conclude that with a Kansei engineering-based configuration system it is possible to help customers find the product corresponding to their objective needs.

4.2 Key Value Attributes Concept

Whereas Kansei engineering deals with how to help customers better get to know their objective needs, the key value attributes concept enables the mass customizer to optimize variety while maximizing the value to the customer. We agree that the product configuration corresponding to the optimal customer value is the variant fulfilling the objective customer needs.

Attributes are defined “…as relatively directly observable physical characteristics of a product or service. Examples are price, colour, weight, etc” (Virens/Hofstede 2000, p. 4). Customer values are, “…in general defined as relatively stable cognitions and beliefs that are assumed to have a strong motivational impact. Examples are ‘security’, ‘happiness’, ‘fun and enjoyment’, etc.” (Virens/Hofstede 2000, p. 4). The personal computer is an ideal example for explaining how customer values differ from one person to another. Computer is a necessity for individuals who value sense of accomplishment, a status symbol for those who value self-respect and a toy for individuals who value fun and enjoyment (Virens/Hofstede 2000, p. 4).

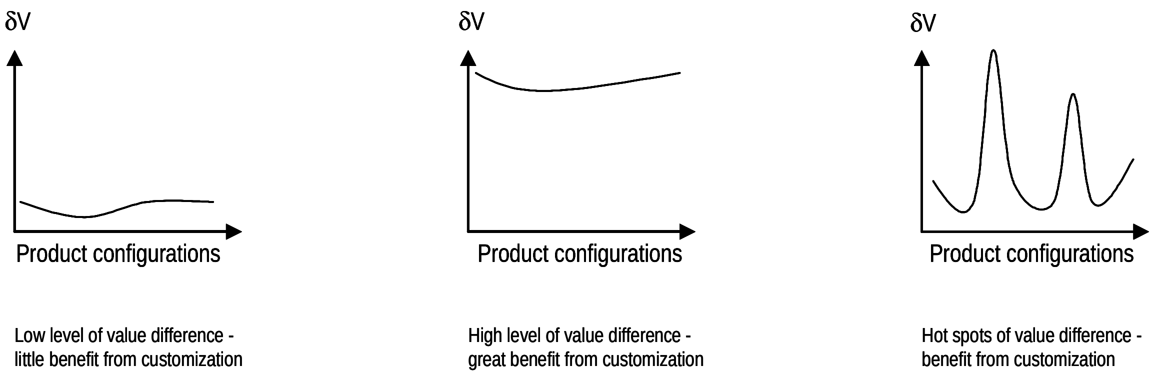
A product configuration is obtained by a unique combination of product attributes. The total set of product configurations is generated by all possible permutations of product attributes. The attributes which represent the greatest perceived value to customers are called *Key Value Attributes*. The perceived value of different configurations varies across the customer base. Although product configurations are discrete, the representation of the customer value by means of a curve makes sense due to the high number of product variants (Figure 11) (MacCarthy et al. 2002, pp. 76).



Source: MacCarthy et al. 2002, p. 78

Figure 11: Conceptual illustration of customer differences

The customer value curves are a representation at a defined point in time T. At a later point in time T+ΔT the value curves can change because of changes in many factors such as tastes and fashion, technological innovations and product maturity. The potential for customization can be deduced from differences between customer values (Figure 12). Comparing customers involves a value difference curve (δV). A low level of value difference across configurations suggests high market homogeneity. Thus, the product can be standardized. High difference levels depict high market heterogeneity and also greater potential for customization (MacCarthy et al. 2002, pp. 78).



Source: MacCarthy et al. 2002, p. 79

Figure 12: The conceptual value difference curve

By analyzing the value difference curves, it is possible to determine which product configurations are presenting high difference levels. For example, when we consider the curve on the right side of figure 12, the key value attributes are those responsible for high spots. These key value attributes have to be recognized in order to be freely customized by customers. For example, if ‘color’ is a key value attribute, then it is valuable to provide a high color variety, in order to increase the probability that customers find the color which contributes to the configuration having the optimal value.

The concept of key value attributes is relevant for mass customization. It delivers interesting approaches regarding how to optimize variety with respect to the real customer needs. Variety which does not contribute to increase value to customers is superfluous and confusing. Furthermore, this concept emphasizes the fact that the attributes to be customized are dynamic and can change over time.

4.3 Problems in Identifying the Objective Customer Needs

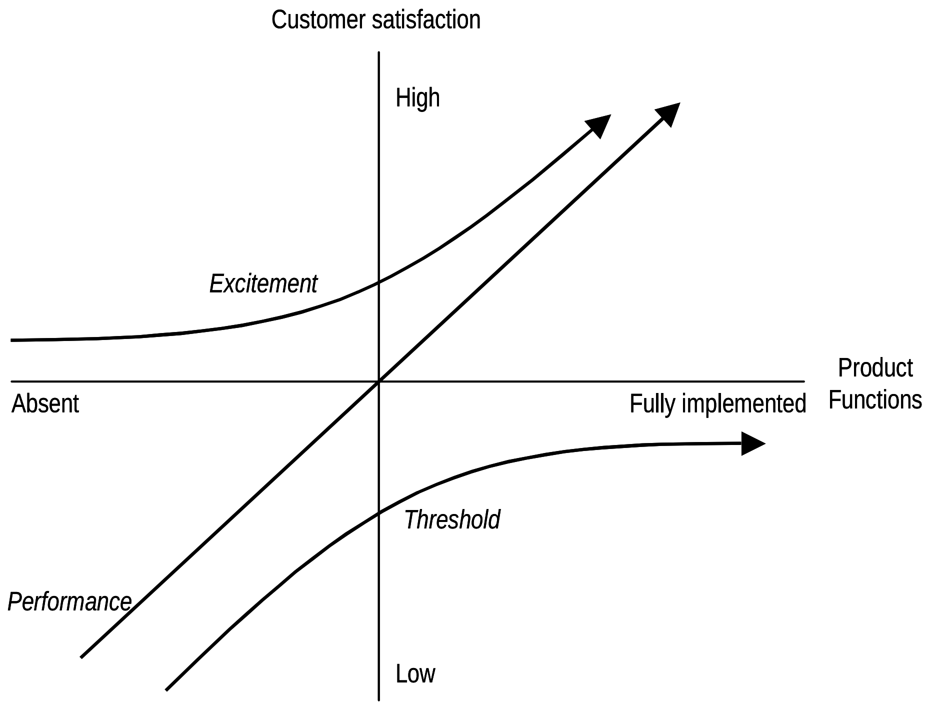
The objective customer needs are difficult to determine. The mass customizer who intends to approach the customer real needs has to completely switch off the communication problems which can arise when customers cannot correctly express themselves or when the mass customizer wrongly interprets the customer needs. These communication problems could be to some extent solved by means of Kansei engineering and by considering the principles of the key value attributes concept.

However, the challenge is how to solve the problem when customers do not know their real needs. An empirical study including four small and medium companies (SME’s) carried out by the Goeteborg University in Sweden shows that the involved companies were disappointed by the results of their customer interviews. The companies expected that their customers would be able to enumerate their needs using product specific terms and to make the sometimes implicit explicit. But, the participants (potential customers) were not able to formulate their requirements and did not propose innovative solutions. The disappointment would have occurred, either because the full potentials of the implemented methods are not tapped or because the available methods are not suitable to understand the complexity of the consumer behavior (Ekstroem/Karlsson 2001, p. 24). The following figure presents the problems related to the identification of the objective customer needs and the potential solutions:

Problem	Potential solution
1. The customers do not know their real needs.	n/a
2. The customers can not correctly express their real needs.	Kansei engineering based configuration systems
3. The mass customizer wrongly interprets customers' requirements.	Key value attributes concept

Figure 13: Problems and potential solutions by considering the objective needs issue

As explained, solving the problem when customers themselves do not know their real needs is complex. In order to detail this problem and to win some approaches for a potential solution, we consider the Kano model, which divides the product attributes into three categories: threshold, performance and excitement (see figure 14).



Source: Berger et al. 1993, p. 4

Figure 14: Kano Model

The threshold (basic) attributes are the "must" attributes in a product. Customers generally do not articulate them and assume that these attributes will be perfectly satisfied by the company. A poor fulfillment of the requirements regarding the basic attributes will lead to extreme customer dissatisfaction. For example, when buying a car, customers naturally expect the availability of a break system which is perfectly operating. The performance attributes correspond to the customer needs which can be verbalized. However, it frequently happens that customers do not properly articulate these needs. A misconception of the performance attributes negatively influences the customer satisfaction. For example, customers are less satisfied with a car which does not provide fuel economy. Excitement attributes are unspoken, unexpected and present latent needs, of which customers are unaware. These attributes lead to an extreme customer satisfaction and provide a competitive advantage. However, when these attributes fail, customers will not be dissatisfied (Berger et al. 1993, pp. 4).

If we assume that no communication problems arise, then the objective customer needs are those fulfilled by the performance and excitement attributes (see figure 15). When communication problems occur, then even the verbalized attributes will not lead to the objective needs. We agree that some of the non-verbalized attributes being partially unknown by customers would be detected when the mass-customizer observes customers by using the product or a similar one. The excitement attributes are the results of innovative and creative ideas of the mass customizer. Ekstroem/Karlsson (2001, p. 24) suggest to keep a permanent dialogue with consumers during product development in order to approach their real needs.

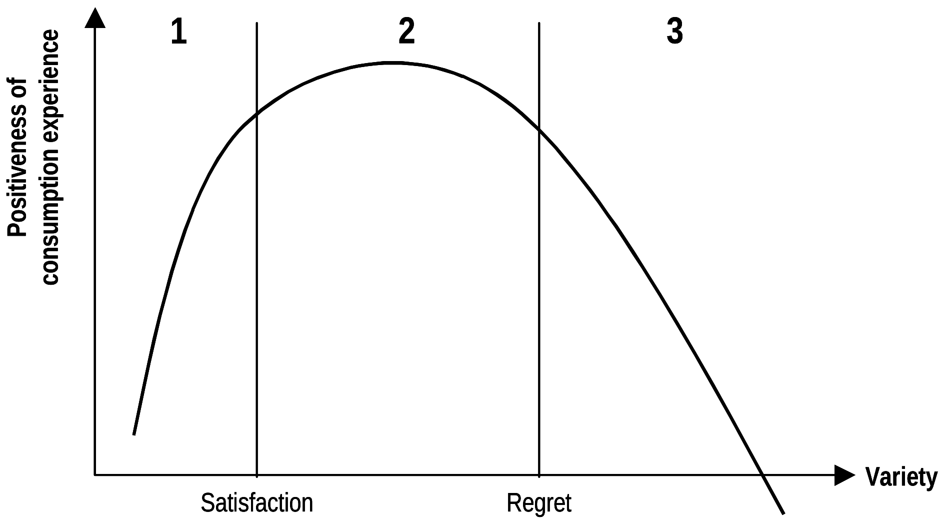
Threshold attributes	Performance attributes		Excitement attributes
	Verbalizad attributes	Non-verbalized attributes	

Attributes fulfilling the *objective* customer needs

Figure 15: Relationship between attribute categories and objective needs by excluding the communication problems

4.4 Approaches from the Consumer Psychology Related to the Variety Problem

Desmeules (2002, pp. 6) has examined the relationship existing between variety and consumer behavior. He provides a graphical model which describes how variety can correlate with the positiveness of a consumption experience when customers evaluate the product variants by cognition (see figure 16). The dependent variable “positiveness of a consumption experience” could be either customer happiness or satisfaction. Whereas customer satisfaction is a post-purchase evaluation of a product or a service, customer happiness extends the meaning of customer satisfaction to include also the shopping experience. In mass customization, the shopping experience refers to customer interaction with the configuration system.



Source: Desmeules 2002, p. 10

Figure 16: Relationship between perceived variety and positiveness of consumption experiences when the evaluative task is performed by cognition

The inverted "U"-shaped relationship between variety and the positiveness of a consumption experience presents three sections. Section (1) indicates that adding new variants increases customer happiness because the likelihood that customers find the variant they are looking for is greater. The point of satisfaction would be reached when all the variants that customers require are available. The variants of section (2) do not have a great influence on the consumption experience and may be either considered or ignored by customers. The end of section (2) refers to the point of regret where customer happiness starts to considerably dive. In section (3), it is assumed that the variants added negatively affects the consumption experience because of stress, frustration and regret. Regret arises owing to the high number of variants, which leads to an information overload. Subsequently consumers would feel that they did not find the optimal solution and that another product configuration would be more suitable for them (Desmeules 2002, p. 10). Iyengar/Lepper (2000) also suppose that in limited-choice contexts people are engaged in rational optimization, whereas in extensive-choice contexts people simply end the choice-making when they find a choice that is merely satisfactory, rather than optimal. Schwartz (2000, p. 21) indicates that by adding new options, the choice situation would be less rather more attractive and that some people would look for the help of e.g. experts, who make the decision for them.

4.5 Final Key Metrics Model

The final key metrics model will integrate all concepts being previously discussed. In order to approach the objective customer needs, it is relevant to conceive a configuration system that helps customers better recognize their real needs. A Kansei engineering based configuration system would increase the likelihood that customers find the product matching their real expectations. The advantage of such a configuration system is to suggest only a manageable amount of variants, which enables to avoid a possible information overload. We consider that the information overload is the principle cause leading either to abort the configuration process or to make a non optimal choice. Furthermore, the configuration system should be flexible so that the proposed variants can be sophisticated and improved by the customers themselves. Customers should have the possibility to make some changes in the products proposed by the configuration system. For the final model, we agree that Kansei engineering is the suitable presentation concept supporting the web appearance and data format of the mass customizer.

The described key value attributes concept is an interesting approach for coping with some communication problems leading to the misconception of customer needs. The mass customizer has to track the evolution of the value difference curves over time. Changes in the curve shapes would suggest that some of the current key value attributes have no longer the same importance for customers and that new value attributes may have more relevance. MacCarthy et al. (2002, pp. 74) distinguish between five factors being responsible for changing value difference curves. These factors are: tastes and fashion, different markets, competitive environment, product technological capability and product innovation, and product maturity. Changing customizable attributes have been already observed in the practice and especially in the automobile industry. Some options that had to be earlier explicitly specified by customers are now serially produced. Therefore, it is relevant that in a period of time ΔT the mass customizer tracks the number of introduced customizable attributes, the number of eliminated customizable attributes and the ratio of customizable attributes at period T+ΔT in comparison to the customizable attributes at period T. The value of ΔT will be different from a mass customizer to another because it basically depends on the product nature. When the customizable attributes frequently change then ΔT should be smaller than when changes are infrequent.

[29] Number of new introduced customizable attributes at period ΔT : $N_n(\Delta T)$

[30] Number of eliminated customizable attributes at period ΔT : $N_o(\Delta T)$

[31] $$R(T+\Delta T,T)=\frac{\text{Number of customizable attributes at T}+\Delta\text{T}}{\text{Number of customizable attributes at T}}$$

$$=\frac{N(T)+N_n(\Delta T)-N_0(\Delta T)}{N(T)}$$

$R(T+\Delta T,T)$: Ratio of customizable attributes at period T + ΔT to customizable attributes at period T
$N(T)$: Number of customizable attributes at period T

The consumer psychology and marketing posit that the customer happiness with the consumption experience (customer satisfaction with the shopping experience as well as with the product after consumption) relates to the extent of offered variety. Therefore, we propose to consider the customer happiness in the final model. High consumer happiness would suggest that the likelihood the offered variety matches the objective customer needs is high. Furthermore, the likelihood that customers configurate the product corresponding to their subjective needs would increase after the point of regret because of the information overload. As said before, customers may break the searching process after they find a satisfactory but suboptimal alternative when they feel overwhelmed with variety. Recapitulating, we can say that customer happiness should be improved by adding variety. But, decreasing customer happiness would suggest that the introduced variety rather confuses and frustrates customers.

In mass customization, it is interesting to keep an eye not only on the customer who is defined as "…visitor or a user who buys something" (Sterne 2002, p. 146), but also on the potential customer. The potential customer is the qualified visitor that "…has the need, the desire, and the means to make a buy" (Sterne 2002, p. 146). The potential customer can come, tries the configuration system and then goes away without completing the buying process. In the final model, we also distinguish between customers and potential customers. Measuring the customer happiness can be based on surveys which are generally infrequent and costly. That is why, in the short run, surveys are not suitable for tracking customer satisfaction. However, the level of customer satisfaction can be deduced using the following key metrics, namely: churn rate, return rate and complaints rate that can be more frequently observed.

[32]

$$\text{Customers churn rate at } \Delta\text{T } (CCR(\Delta T)) = \frac{NOLC(\Delta T)}{NOC(T) + NONC(\Delta T) - NOLC(\Delta T)}$$

$NOLC(\Delta T)$: Number of lost customers at ΔT
$NOC(T)$: Number of customers at T
$NONC(\Delta T)$: Number of new customers at ΔT

Source: Sterne 2002, p. 146

[33]

$$\text{Return rate at } \Delta\text{T } (RR(\Delta T)) = \frac{\text{Number of returned products}}{\text{Number of delivered products}}$$

Source: Piller 2002, p. 16

[34]

$$\text{Complaints rate at } \Delta\text{T } (CR(\Delta T)) = \frac{\text{Number of complaints } (\Delta\text{T})}{\text{Number of deliveries } (\Delta\text{T})}$$

By computing the key metric referring to the complaints rate, the mass customizer must consider that "…in general only about 5% of unsatisfied customers ever complain" (Walczuch/Hofmaier 1999, p. 7). To have an idea about the actual value, the computed value must be respectively amplified. Furthermore, whether a certain customer should be considered as a migrated one, this depends on the own definition of the mass customizer. For example, customers who do not repurchase for a certain period of time can be considered as lost customers.

The potential customer happiness only refers to the shopping experience because no buying takes place. In order to determine the potential customers, the mass customizer has to establish a certain profile of them. "A qualified visitor sees a certain number of pages or downloads the white paper or plays the game" (Sterne 2002, p. 144). The mass customizer has to track the number of these potential customers. With the aid of log files, it is possible to analyze why the visitors did not complete the buying process.

[35]

$$\text{Percentage of potential customers (PC)} = \frac{\text{number of potential customers}}{\text{number of customers} + \text{number of potential customers}} \times 100$$

Furthermore, happy customers do more business and purchase often more. The correlation between happiness and profits is direct because the happier the customers are, the more they spend. As a result, sales will grow (Brown/Gulycz 2002, p. 34). The potential customer happiness has a direct effect on the growth of the customer basis. The corresponding suitable key metrics are assigned to each of the explained parameters which are repurchase, growth of the customer basis and sales.

[36] $$\text{Repurchase rate at } \Delta\text{T } (R\ (\Delta T)) = \frac{\text{Repurchase through extisting customers } (\Delta\text{T})}{\text{New customers } (\Delta\text{T})}$$

Source: Piller 2002, p. 15

[37] $$\text{Growth rate at } \Delta\text{T } (GR\ (\Delta T)) = \frac{NONC(\Delta\text{T})}{NOC(T)}$$

Source: Sterne 2002, p. 146

[38] $$\text{Sales volume } (\Delta\text{T}) = \text{number of sold units } (\Delta\text{T})$$

The final key metrics model for mass customization is represented by the figure 17. The customizable attributes are influenced by the product architecture properties stemming from the preliminary key metrics model. In addition to the customizable attributes, the potential customer happiness is also influenced by the web appearance and data format. The customer happiness is influenced by three factors which are the customizable attributes, the web appearance and data format, and the delivery time reliability. An empirical study of online shopping carried out by Ho and Wu (1999, p. 7) shows that the logistical support has the strongest correlation with customer satisfaction. This approves the importance of the delivery reliability on customer happiness. Furthermore, the customizable attributes have a great influence on the used variety and on the components commonality. The influence of the customizable product attributes on the used variety is trivial because by changing the customizable attributes the offered variety and also the perceived variety change. The influence on the components commonality is also obvious because, for example, the introduction of an option into the serial production and canceling it from the list of the customizable options automatically increases the components commonality. However, introducing a new customizable attribute decreases the commonality between components. MacCarthy et al. (2002, p. 81) suggest that the cumulative value of the customizable attributes should be opposed to the cumulative costs of these attributes. The optimal number of customizable attributes results by maximizing the value to the customer, while minimizing the attributes' costs. However, they do not propose any method dealing with the determination of the corresponding costs. These costs comprise complexity costs which are hardly to compute. The proposed final key metrics model visualizes the correlations existing between external and internal complexity. If the mass customizer intends to introduce new customizable attributes, then he should examine how the components commonality and the related key metrics' values change.

Whereas the happiness of the potential customers contributes to the expansion of the new customer base, the customer happiness directly influences the repurchase rate. Furthermore, the customer growth rate and the repurchase influence sales, which again influence the work-in-process inventory turnover presented by the preliminary key metrics model.

The goal of the model distinguishing between the objective and subjective customer needs was to provide an approach related to variety steering in mass customization from customer perspective. The concepts presented in this chapter, namely Kansei engineering, the key value attributes concept and the insights gained from the consumer psychology provide some approaches to solve the variety problem from customer perspective arising because of the discrepancies existing between the objective and subjective needs. The key metrics which are determined aims at extending the preliminary key metrics to include customer considerations. Thus, the final key metrics model is a comprehensive model emphasizing on both internal and external complexities.

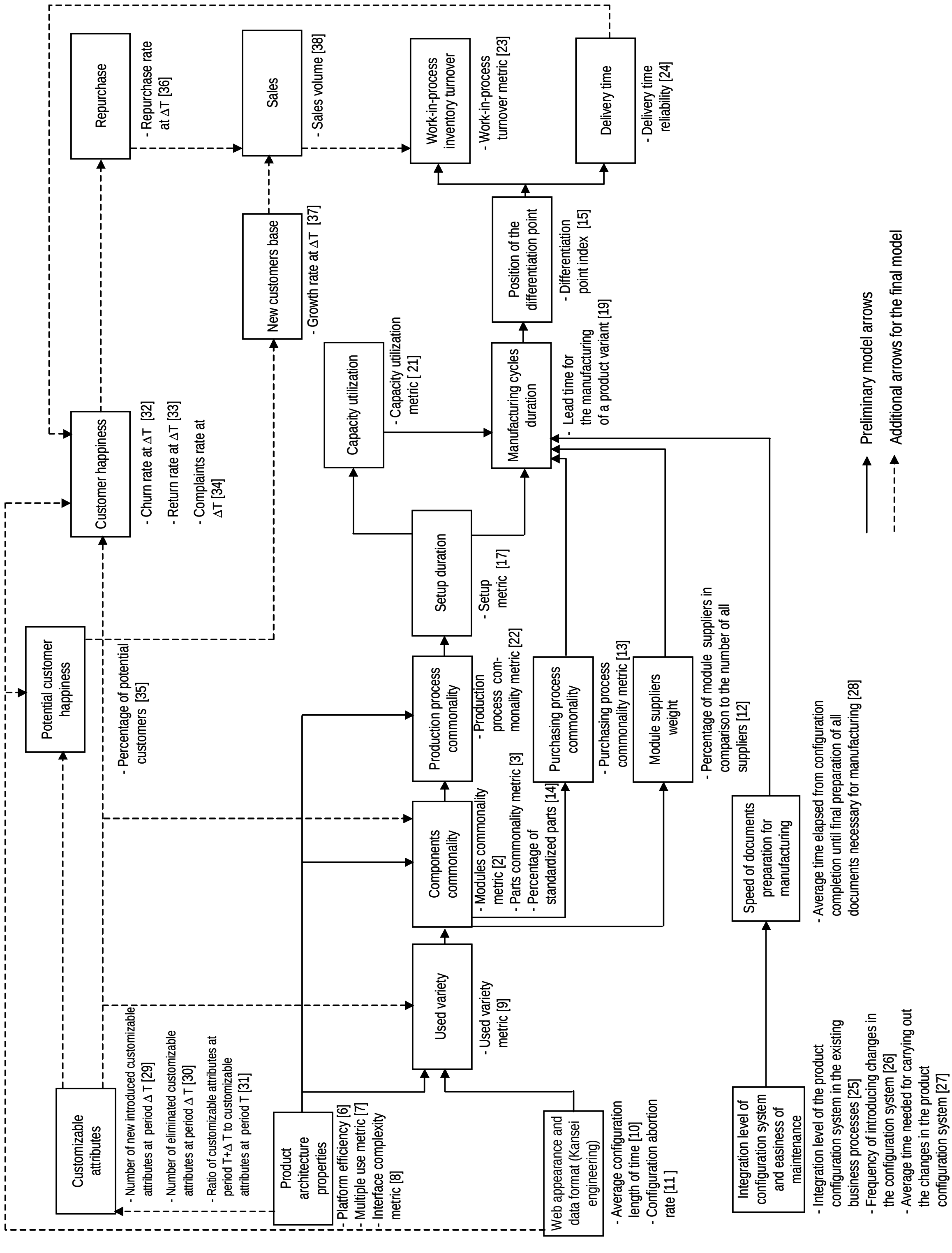


Figure 17: Final key metrics model for mass customization

5 Conceptual Application for Variety Steering in Mass Customization

In order to explain how to use the key metrics system to support variety steering we develop a conceptual application. This application presupposes that we dispose of two hypothetical units capable of examining the existing attributes, picking out and suggesting critical ones. The first unit (O) recognizes the product attributes contributing to the objective customer needs. The preferences related to these attributes are very different from one customer to another and present high value differences. The second unit (S) is capable of recognizing which product attributes confuse customers or are over-engineered.

The attributes corresponding to the minima of the value difference curves are those recognized by (S) and could have high, middle or low customer values. The common characteristic is that each attribute is nearly appreciated by the same customer value. The attributes having high values must be kept in the production program. However, their customization is not necessary. The attributes with middle and low customer values should be carefully examined in relation to their corresponding costs, in order to decide whether it is valuable to serialize or to eliminate them.

Before adding the new customizable attributes suggested by (O) to the production program, the mass customizer should carry out the first test consisting of checking out, whether these attributes can be produced by means of the existing production processes. If some attributes require new investments, then the mass customizer has to consider the outsourcing alternative and if there are suppliers in the supply chain being able to carry out the corresponding customizing process of these attributes or deliver the required material, components or modules. If new investments are necessary, then this is a strategic decision that should be economically examined by the upper management.

We propose to divide the final key metrics system which is described by figure 17 in 4 zones as shown by figure 18. Zone I consists of the aggregate referring to the customizable attributes. Zone II is composed of the aggregates related to the product architecture and configuration system. Zone III comprises the key metrics aggregates related to the evaluation of the internal variety-driven complexity, namely: used variety, components commonality, production process commonality, purchasing process commonality, modules suppliers weight, setup duration, capacity utilization, manufacturing cycles duration, position of the differentiation point, work-in-process inventory turnover and delivery time. The key metrics of zone IV are potential customer happiness, customer happiness, repurchase, new customers base and sales.

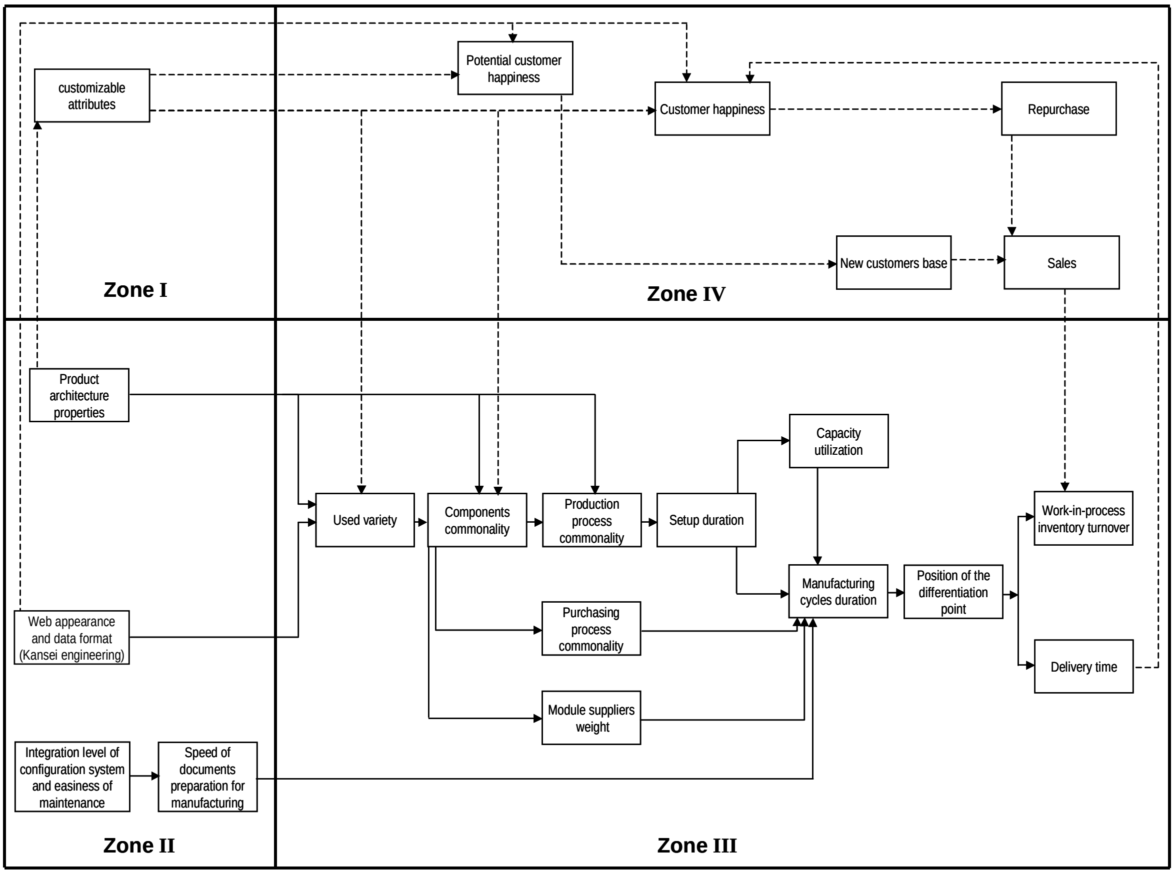


Figure 18: A suitable key metrics grouping for variety steering

At a point in time T the decision concerning the introduction of the attributes proposed by (O) and/or the serialization or elimination of the attributes proposed by (S) directly impact the key metrics of zone I and zone III. The key metrics of zone III provide the basis for the second test. The key metrics' values examination will provide an idea to what extent the internal complexity changes. When complexity considerably increases, one or some attributes have to be abandoned. Therefore, we recommend classifying these attributes according to the customer values. The attribute with the lowest mean value among all customers can be eliminated, and then the resulting impact on the key metrics of zone III has to be analyzed. If the complexity is still high, then the mass customizer has to carry out a second iteration and eliminate the next attribute with the next lowest mean customer value. The iterations continue until the resulting complexity is evaluated as acceptable. Furthermore, the values taken by the key metrics of zone III strongly depend on the key metrics of zone II which are considered to be less sensitive than the other key metrics. So it is conceivable that the successive elimination of many attributes does not decrease the internal complexity. That is why it would be necessary, for example, to improve the integration level of the configuration system into the business processes, which is generally associated with high investment costs.

The attributes retained after the complexity test carried out with the help of the key metrics of zone III are the subject of a third test. The purpose of this test is to compare the cost positions of the mass customizer to those of the competitors regarding these attributes. It is not suitable to compare the cost positions of each attribute with the corresponding one of the competitor. Therefore, we recommend comparing the cost positions of a bundle of attributes with those of competitors because some attributes in the bundle can have a bad cost position, whereas the total cost of the bundle is advantageous.

The attributes succeeding all the three described tests can be introduced to the production program. The key metrics of zone IV point out how in a period of time (ΔT) following the introduction of the new product variants, the customer reacts to this new variety. Therefore, it is important to switch off all the effects of other changes on these metrics to analyze only the effect of variety. If customer happiness decreases, this suggests that customers do not appreciate the introduced variety. Therefore, the units (O) and (S) should be revised or the web appearance and data format of the configuration system have to be improved.

This application for variety steering in mass customization shows how it is possible to manage internal complexity, while keeping a maximal orientation on the customer needs. From the key metrics “customer happiness” and “potential customer happiness”, it is also possible to draw some conclusions as to whether the offered variety moves towards fulfilling the objective or only the subjective needs of the customers. For example, bad values for „customer happiness“ and „potential customer happiness“ would suggest that the offered variety to a great extent corresponds to the subjective needs which rather confuse the customers and only contribute to a satisfaction which is suboptimal.

6 Conclusion

In this paper, we show that variety steering in mass customization has to take into account an internal and an external perspective. The model distinguishing between the objective and subjective customer needs present some approaches regarding how to orientate variety on the real customer needs. The subjective needs are the individually realized and articulated requirements, whereas the objective needs are the real ones perceived by a fictive neutral perspective.

In order to solve the variety-driven complexity problem in mass customization, we opt for the development of a key metrics system solution. After analyzing the main sub-processes in mass customization, we determine the basic complexity key metrics. Some key metrics stem from the corresponding literature and some are additionally devised. The resources needed for computing these key metrics are considered and should be kept at a low level. Furthermore, the required data should already exist in the company. The sub-processes based key metrics are then presented in a preliminary key metrics system model. This model shows that the internal complexity depends not only on the product and its architecture but also on the configuration system and its integration level in the business processes. We conclude the relevance of the configuration system for reducing internal complexity.

The proposed preliminary key metrics model has rather an internal orientation. Solving some aspects of the problem arising when distinguishing between the objective and subjective customer needs can be reached through concepts such as Kansei engineering and key value attributes. The problems when customers do not know their real needs are complex and present an issue for further research. The consumer psychology also provides interesting approaches for solving the external complexity perceived by customers, which can lead to information overload and suboptimal decision making. In order to approach the objective customer needs, the configuration system has a great potential to help customers better get to know their real needs. We also believe that further research is required in the field of the interaction between the configuration system and the customer to help customers recognize their real needs in spite of high variety.

The final model builds upon the preliminary model and expands it with the customer perspective. The final model is comprehensive and evaluates both internal and external perspectives of complexity. It suggests that high variety has no sense, when it cannot be perceived by customers. Furthermore, a conceptual application for variety steering in mass customization has been developed on the basis of the final key metrics model. We show how this model can support decisions related to variety steering. In addition, further research is required in order to concretely conceive the hypothetical units (O) and (S). We are convinced that the data which arise during the interaction between customers and configuration system can be explored to determine the characteristics of these two units.

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