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“Measuring the degree of mass customization: A product architecture modularization
perspective”

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Abstract

This paper examines how mass customization can be measured in terms of product architecture modularization. Mass customization is interpreted as a process to produce customized goods at low cost, which has enabled many companies to penetrate new markets and capture customers personal needs that are not met by standard products and services. Mass customization is enabled through modular product architectures, from which a wide variety of products can be configured and assembled. Product architecture modularization is concerned with system decomposition, selection of components and how they are linked with each other without compromising system integrity. In order to understand the implications of product architecture modularization for mass customization, the *modularization function* is explored by applying and simulating it to a hypothetical system. Based on this exercise and sources from the literature, a new model is introduced. Furthermore, theoretical and engineering management implications are discussed.

1. Introduction

The world is very much governed by technology in the form of computers, TV, mobile phones, cars, ATMs, etc. Through technological solutions, innovation in products, processes and services are created and advanced. For companies, innovation management brings various rewards, such as increased profitability, recognition, and hopefully increased market share.

It often takes a long time for new products to be developed, evaluated, tested, manufactured, marketed, and subsequently sold in the market. Positive return on

investment of a product may not show up in corporate accounting books until many years after its introduction to the market place (Aaker and Jacobson, 1994; Hodder and Riggs, 1985). The high degree of uncertainty and risk inherent in new product development (NPD) projects pose enormous difficulty for managers to make rational decisions regarding technology selection of product platforms and architecture strategies for next-generation of product families. Furthermore, the complexity of NPD and innovation management policies often extends to include other members of the supply chain. These reasons make return on investment of NPD projects extremely difficult to assess.

One phenomenon that is making the supply chain even more difficult to manage is mass customization, which forces firms to re-examine their NPD and logistics strategies. This paper extends the *modularization function* (Mikkola and Gassmann, 2003; Mikkola, 2006) to measure the degree of mass customization embedded in product architectures.

This paper is organized as follows. Firstly, a literature on mass customization and modularization is reviewed. Next, the steps describing how *modularization function* is modified for mass customization is introduced. Finally, discussion and proposals for future research is are presented.

2. Mass Customization

The notion of mass customization emerged in the late 1980s, and generally, it emphasizes the need to provide outstanding service to customers by providing products that meet customers' individual needs through unique combinations of modular components (Feitzinger and Lee, 1997; Gilmore and Pine, 1997; Pine, 1993). The goal of mass customization is to produce customized goods (to achieve economies of scope) at low

costs (to gain from economies of scale). It allows companies to penetrate new markets and capture customers whose special or personal needs could not be met by standard products (Lee, 1998). Product varieties are driven by customer demand. The capability to co-design and/or to co-produce products with customers provides mass-customizers with the ability to capture valuable new knowledge. This also means that the supply chain should be re-configured for mass customization (Salvador et al., 2004; Mikkola and Skjøtt-Larsen, 2004). According to Pine (1993) the best way for achieving mass customization is by creating modular components that can be configured into a wide variety of end products and services. High commonality of modules lowers inventory levels and reduces risks of obsolete inventories (van Hoek and Commandeur, 1998), hence lowering inventory costs. Mass customization has been implemented with computers, Levi's jeans, bicycles, Nike shoes, Smart cars, and many more products.

2.1. Mass Customization for Logistics

One central feature of mass customization for logistics is postponement. According to Lee (1998) postponement is about delaying the timing of crucial processes in which end products assume their specific functionalities, features, and identities. Such a means of customization takes place after some key information about the customers' specific needs or requirements is obtained. The delay of the customization of the end product requires that the information about the customers' needs be captured quickly and accurately. The logic behind postponement is that risk and uncertainty costs are tied to the differentiation of goods (i.e. form, place, and time) that occurs during manufacturing and logistics operations.

Outsourcing of product designs and/or manufacturing processes is tightly dependent on how products are designed. *Design for postponement* is one such strategy. It refers to design of the products or the processes so that postponement is possible in order to counteract the complexity and uncertainty factors that paralyze supply chains. One type of postponement closely related to modularization is *form postponement*, which calls for a fundamental change of the product architecture by using designs that standardize some of the components (hence changing the form of the product architecture) or process steps. In order for postponement to be successful, products or processes should be modular in structure (Lee, 1998). In other words, product modularity requires module interface to be redesigned so that they can easily be assembled and tested as a total unit. Furthermore, because postponement strategies involve product development and many members of the value chain, collaboration becomes inevitable between multiple functions (e.g., cross-functional integration) or organizations (e.g., collaborative efforts among multiple firms).

One of the aims of the form postponement strategy is to retain product commonality as far downstream in the supply chain as possible. The degree of product commonality, or the degree of substitutability (especially when unique components are considered), is deeply rooted in the design of modular product architectures.

2.2. Platform & Product Architecture Modularization Strategies

Increasing number of firms are applying platform strategies to achieve economies of scale while creating customization of their products. For example, Volkswagen produces the following car models based on a common platform (Muffatto and Roveda, 2000):

Skoda Octavia, Seat Leon, VW Golf, Audi A3, and Audi TT. Ford now uses the same 'luxury platform' to produce Lincoln, Jaguars and Volvos (Gartman, 2004). The product price and generic strategy (ranging from cost leadership to differentiation) determine the differentiation between the models. Product platform provides the basis for the product architectures and related product families. The basic relationship between product platform, product family and respective variations of end products is illustrated in Figure 1.

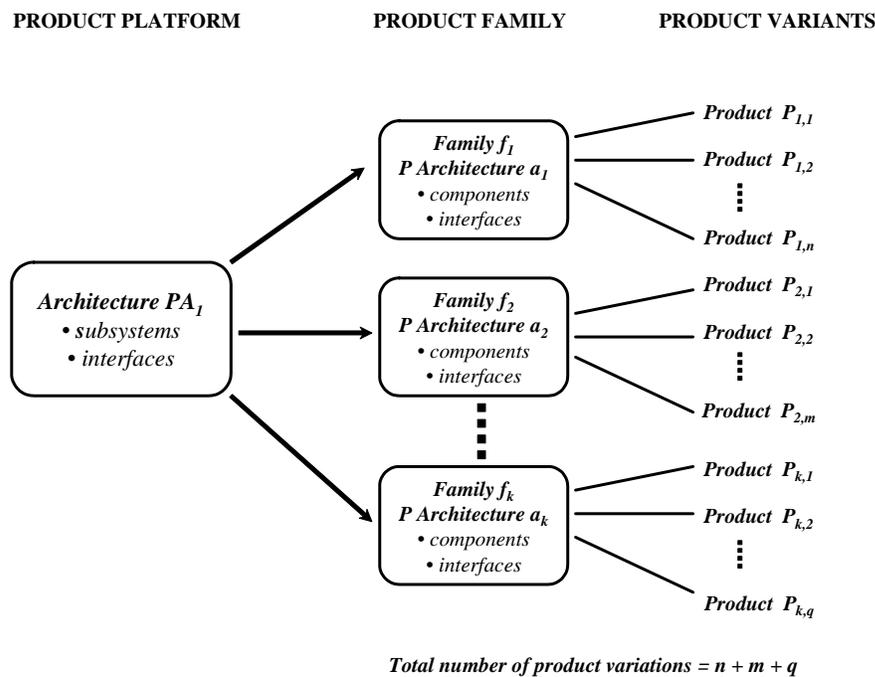


Figure 1. Product Platform, Product Family, and Product Variants.

For a given product platform, a number of product families [e.g., f_1, f_2, \dots, f_k] can be generated, each with its own unique architecture [e.g., a_1, a_2, \dots, a_k]. Based on one product family architecture, many different products are created. For example, family f_1 with product architecture a_1 can produce n products, and family f_2 , m products, and so on.

For example, the platform for *Audi A4* is the basis for *VW Golf*, the new *Beetle*, and *Bora* product families (or sometimes labeled as brands) (Lung et al., 1999).

In order to implement a platform strategy, product architecture strategies have to be devised, which are closely related to the way systems are decomposed, the selection of components to be used and how these components are linked with one another.

Architectural design decisions consider various trade-offs, and there are no optimal designs. Subsequently, most optimization models offer limited insights. Hence, the focus is not to find the optimal level of modularity in product architectures, but to understand the fundamental relationships shared between components and respective interfaces as well as the tightness of coupling shared among the components. The goal is also to gain a better understanding about the role of unique components (to delay imitation and sustain competitive advantage) and their substitutability (to gain from economies of scale) in product architectures, which has direct implications for mass customization, and subsequently SCM.

3. The Modularization Function Modified for Mass Customization¹

In order to understand the implications of product architecture modularity for mass customization, the *modularization function* (MF) introduced by Mikkola and Gassmann (2003) is explored (Equation 1). MF is a mathematical model that measures the degree of modularization embedded in product architectures. The following key factors define the degree of modularity $[M(u)]$ with respect to the number of unique components $[u]$

¹ This section is extracted from Mikkola (2007).

embedded in a given product architecture: components [N and u], degree of coupling [δ], and substitutability factor [s].

$$M(u) = e^{-u^2/2Ns\delta} \quad (\text{Equation 1})$$

Product Architecture Modularity, $M(u)$ – The interpretation of MF is summarized as follows. A given product architecture has N components that are the sum of standard and unique components [$N = n_{STD} + u$]. The specific ways in which components are linked through interfaces [k] create a certain degree of coupling [δ], which is approximated as the average number of interfaces per component, $\delta \sim (k/n)$. The impact of the substitutability of unique components in the product architecture modularity is captured by the substitutability factor [s] estimated as the total number of families, in which the unique components are used, divided by the average number of interfaces required of functionality, $s \sim (n_{PA}/k)$. Due to interface compatibility uncertainties imposed by unique components, the lower the number of unique components the higher the degree of modularization. Hence, a perfect-modular product architecture [$M(u) = 1.0$] does not have any unique components. Unique components used across product families have a higher substitutability factor (hence benefiting from economies of substitution, reusability, and commonality sharing) than those dedicated to one specific product family. This increases the degree of modularity. MF shows that the combined effect of variables varies exponentially according to the set of unique components. Every time the composition of unique components is altered, the degree of modularity also changes. In many cases, the introduction of unique components requires changes in other parts of the product architecture, hence changing the values of N and δ . If one simply assessed the degree of

modularity based on the number of components (regardless of whether they are standard or unique) and ignored the effects of interfaces (captured in δ and s), s/he may not learn why some systems are more modular than others.

Modularization function measures the degree of modularity embedded in product architectures. However, the relationship between it and mass customization and how it can be measured are not so obvious. Therefore, the following model, which is based on $M(u)$, is proposed to measure the degree of mass customization:

$$MC[M(u)] = me^{-u^2/2Ns\delta} \quad 0.0 \leq m \leq 1.0$$

Where m is an indicator of the degree of product variety present in a given product architecture, which is reflected on the number of components that are used for creating product variety:

$$m = \frac{y_1 n_{STD-NON-CUST} + y_2 n_{STD-CUST} + y_3 u_{NON-CUST} + y_4 u_{CUST}}{N}; \quad 0.0 \leq y_1, y_2, y_3, y_4 \leq 1.0$$

$$N = n_{STD-NON-CUST} + n_{STD-CUST} + u_{NON-CUST} + u_{CUST}$$

$$y_1 = \frac{n_{STD-NON-CUST}}{\sum n_{STD-NON-CUST} \text{ (from aggregate MPS)}} \quad y_2 = \frac{n_{STD-CUST}}{\sum n_{STD-CUST} \text{ (from aggregate MPS)}}$$

$$y_3 = \frac{u_{NON-CUST}}{\sum u_{NON-CUST} \text{ (from aggregate MPS)}} \quad y_4 = \frac{u_{CUST}}{\sum u_{CUST} \text{ (from aggregate MPS)}}$$

$n_{STD-NON-CUST}$: number of non-customizable standard components

$n_{STD-CUST}$: number of customizable standard components

$u_{NON-CUST}$: number of non-customizable unique components

u_{CUST} : number of customizable unique components

Where y_1 , y_2 , y_3 , and y_4 are contribution percentages per component type that is used in all production lines, which can be obtained from the BOM and the master production schedule (MPS). The BOM lists the quantity of all the components used in a given product, including respective types and prices. The MPS lists the volume of components needed in production to satisfy demand. With MPS one can determine how often a particular component is shared with other products. The model is an attempt to capture the relationship between product architecture modularity and mass customization in terms of product variety realized through different components. The best scenario takes place when there is a high percentage of all types of components that are also used by other products to create customization ($m = 1.0$), in which case the result will be the same as the value obtained from the modularization function, $M(u)$. The model basically reflects the possible difficulties firms may face when they embark on mass customization without understanding the impact of product architecture modularity, especially about the strategic implications imposed by unique components. The graphical illustration of the modified modularization function is shown in Figure 2.

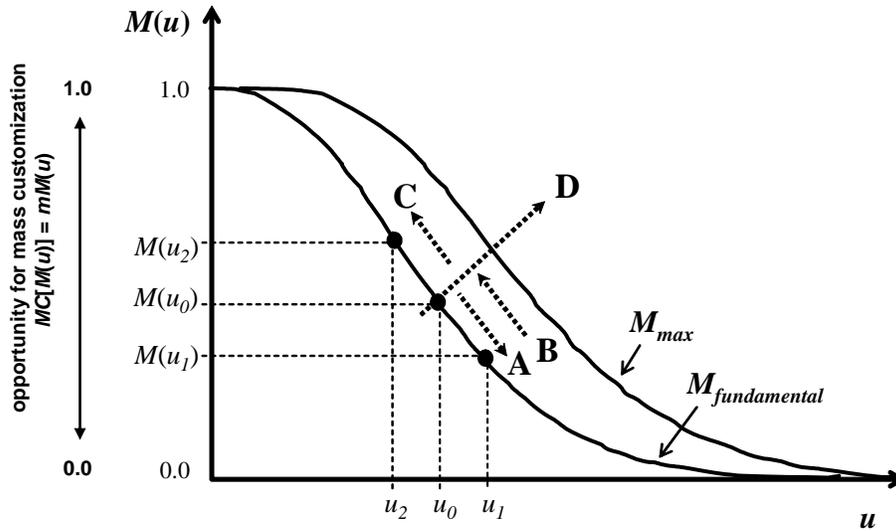


Figure 2. Representation of modularization function modified for mass customization.

Depending on the customization strategies pursued by the firm, $MC[M(u)]$ provides a systematic way of analyzing them. Some companies are more concerned with the long term survival of their innovations. Such behavior is mostly observed with firms with mass customization strategies that are more dependent on upstream activities of a supply chain, such as with build-to-order and engineer-to-order components. In this case, it is more important for these firms to understand the impact of unique components and related possibilities for customization. If the product architecture is relatively modular, it will have a high $M(u)$ value, but if most of its components do not contribute to the customization of the products (from the firm's perspective) then we would expect to have a low value for m , hence decreasing the overall $MC[M(u)]$ value.

$MC[M(u)]$ and $M(u)$ focus on push strategies, in which the amount of customization allowed by a given product architecture is determined by the firm and not the customer. A product architecture can be extremely modular [high $M(u)$], but if only a handful of

components are used for creating customization, its real value is less than a similar product architecture that has higher value of m (hence lower $MC[M(u)]$). $MC[M(u)]$ may be a useful tool for reaching consensus among different functional areas of a firm that are involved with mass customization strategies. The NPD and production engineers are probably the people who should carry out the calculations and plot the functions, as they have the access to BOM [needed to calculate $M(u)$] and MPS (needed to calculate m). Once the functions are plotted, $MC[M(u)]$ can be used as a communication tool to reach consensus about possible misunderstandings and to generate new strategies against competitors (through reverse engineering, for example). Consensus between NPD, production and marketing is the first step a firm must settle before a mass customization strategy can have a chance for success in the market place.

Movement A indicates the firm's ability to incorporate unique components into product architecture designs, such as upgrading and replacing old technology with modular innovations. Movement B captures the learning effect of new components over time. In other words, it indicates the speed in which a firm can adopt to the changes required by the introduction of components into the product architectures to fit the organizational processes, which is highly dependent on a firm's production capabilities. Movement C is observed when product architectures become too modular, and firms react to this by integrating modular components into a new innovation. Movement D indicates the amount of product variety and customization that is allowed by the product architecture. Sometimes, best and worst case $MC[M(u)]$ graphs can be generated. In Figure 2, $M_{fundamental}$ indicates the basic configuration and M_{max} represents the most complex configuration.

For products that are customized closer to end customers (downstream activities), standard components (often due to economy of scale effects) play a more crucial role than unique components, such as make-to-stock and bundle-to-order components. In this case, the ability to mix-and-match components is more relevant than creating specialized customization through new product development solutions. Firms pursuing this strategy are often more concerned with short-term survival through cost savings rather than from long-term capability development of their product architectures by introducing innovations that are difficult to be imitated by the competitors.

4. Conclusion and Discussion

This paper explored how mass customization can be measured from a product architecture modularization perspective. It described how mass customization is dependent on postponement strategies pursued by the firms, which calls for a fundamental change of the product architecture by using designs that standardize some of the components (hence changing the form of the product architecture) or process steps.

One important topic related to mass customization that deserves deeper investigation is related to product design and logistics configuration for outsourcing. Developing platforms in cooperation with other firms is difficult due to complexities generated by organizational, technical and managerial variables (Lundback and Karlsson, 2005). Component outsourcing is possible when product architecture is decomposed in such a way that new product development and/or manufacturing activities can be carried out independently by the suppliers. Furthermore, new production forms have emerged to deal with mass customization and modularization issues, such as Volkswagen's modular production factory in Brazil and Smart Car production in France and Germany. These

new production paradigms have changed how supplier-buyer relationships are handed. This often shifts the order decoupling point (Olhager, 2003; van Donk, D.P., 2001; Mason-Jones and Towill, 1999) along the supply chain.

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