Chapter 4
NPD-SCM Alignment in Mass Customization

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Abstract This chapter aims to develop a new product development supply chain management alignment framework for mass customization. A case study conducted in industry motivates this framework. Variety, modularity, and innovativeness are the product features that should be taken into account when studying alignment in a mass customization setting. From the supply chain viewpoint, configuration, collaboration, and coordination complexities are the variables that matter. We formulate ten propositions explaining the relationships between the variables of the framework. It must be noted that innovativeness, a variable that has so far been neglected with respect to the alignment question, plays a critical role in supply chain management decisions.

Abbreviations

BOM Bill-of-materials
JIT Just in time
NPD New product development
OEM Original equipment manufacturer
SCM Supply chain management

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4.1 Introduction

Mass customization is a business strategy that aims to produce and distribute customized goods at costs that are low enough to target a mass market (*e.g.*, Abdelkafi 2008, Da Silveira *et al.* 2001, Pine 1993); it requires a high degree of flexibility in manufacturing (Fogliatto *et al.* 2003) and along the supply chain. The application of mass customization is not a mere adaptation of available processes to a new environment; the strategy imposes radical changes in the way of doing business (Brown and Bessant 2003). Very frequently, variety proliferation is mentioned as the biggest problem challenging the pursuit of mass customization. High variety can induce operational inefficiencies (*e.g.*, Da Silveira 1998), sometimes leading the manufacturing firm to give up the entire customization program.

Researchers investigated the relationship between variety and supply chains (*e.g.*, Fisher 1997, Randall and Ulrich 2001). The study of this relationship is relevant because of two reasons. First, since the variety created at the design phase is manufactured and distributed within the supply chain, it determines a high portion of the costs of operating the supply chain. Second, the magnitude of the operational effects of variety on the supply chain depends on the adequate choice of supply chain practices, *e.g.*, outsourcing, supply chain structure, positioning of the production sites and warehouses (Blackhurst *et al.* 2005), and supply chain strategy (Childerhouse *et al.* 2002). In other words, for a given level of variety, a particular supply chain practice leads to a better operational performance than another.

To satisfy customers' requirements better and to stay competitive, mass customization companies continuously update their product offers. The increased rate of new product introductions calls for adaptations of the supply chain. Therefore, supply chain management (SCM) and new product development (NPD) should be aligned, so that new products can be transported and delivered at the targeted cost, time, and quality. NPD-SCM alignment allows the manufacturing firm to overcome problems such as product unavailability due to insufficient capacities of supply, production, and/or distribution (Van Hoek and Chapman 2007).

So far, however, there is no comprehensive framework that determines the right actions leading to NPD-SCM alignment in mass customization. The strategy requires, *per se*, a very responsive supply chain and the application of specific design rules. Alignment leverages supply chain capability enhances the effectiveness of product introduction and firm performance (Van Hoek and Chapman 2006). Management practice needs a tool that outlines the supply chain areas more impacted by the introduction of new products in mass customization. The tool aims to support the identification of recommendations that enhance supply chain performance. This chapter aims to fill this gap in the literature.

In our analysis, we concentrate on the focal firm, which develops the new product and designs the supply chain. The remainder of this chapter is organized as follows. In the next section, we discuss leading literature on NPD-SCM alignment and mass customization. Section 4.3 discusses the framework, while formulating propositions. The final section concludes and provides directions for future research.

4.2 Literature Background

Mass customization defines the frame of analysis, whereas NPD-SCM alignment represents the main investigation area. Mass customization imposes requirements on NPD and SCM simultaneously.

4.2.1 NPD-SCM Alignment

NPD is the process of transforming a market opportunity and a set of assumptions about product technology into a marketable product (Krishnan and Ulrich 2001, Weelwright and Clark 1992), whereas SCM is the approach to designing, organizing, and executing all the activities along the value chain from planning to distribution, including the network of suppliers, manufacturers and distributors (Childerhouse *et al.* 2002, Vonderembse *et al.* 2006).

SCM and NPD are necessarily related because, at the end, the supply chain produces and delivers end products that are the output of product development. Most NPD-SCM alignment models assume that product design decisions have already been made (Simchi-Levi *et al.* 2002). Recently, an increasing emphasis on the coordination of SCM and NPD has become noticeable (Hult and Swan 2003, Rungtusanatham and Forza 2005). The approaches that tackle this issue are either NPD-oriented or SCM-oriented (Table 4.1).

Table 4.1 NPD and SCM-oriented approaches

Criteria \ NPD-SCM alignment approaches	NPD-oriented approach	SCM-oriented approach
Main focus	Product development	Supply chain
Problem statement	Given the supply chain constraints, find an adequate product design	Given the product design, find the best supply chain that optimizes performance
Solution	An optimal BOM or product architecture	The optimal supply chain strategy or supply chain structure

The NPD-oriented approach may be called "design for supply chain management" (Lee and Sasser 1995); it anticipates supply chain constraints at the early stages of product design. Decision support models of the NPD-oriented approach either consider bill-of-materials (BOM) or product architectures. Models using BOM express relevant costs such as transportation and inventory costs as a function of the product structure. Then, the cost function is optimized to find the best BOM for a given supply chain (Blackhurst *et al.* 2005, Huang *et al.* 2005, Lee and Sasser 1995). Product architecture-based models are used more frequently. Product architecture is "the scheme by which the function of the product is allocated to physical components" (Ulrich 1995, p. 420). Krishnan and Ulrich (2001) argue that the trade-offs between product, process, and supply chain design are better addressed by considering product architectures (modular *vs.* integral) than BOM. Many models analyze the relationships between product architecture characteristics and supply chain decisions (Fixson 2005). Some models deal with the selection of the appropriate sourcing strategy (Novak and Eppinger 1998); other models focus on postponement and the placement of the differentiation point in the supply chain (Feitzinger and Lee 1997).

SCM-oriented literature proposes two types of approaches. The first approach defines supply chain strategy (*i.e.*, lean, agile, or hybrid) depending on product and market-related variables such as demand variability, variety level, and demand volumes (Vonderembse *et al.* 2006, Huang *et al.* 2002, Fisher 1997). The second approach analyzes the impacts of various product structures on supply chain design decisions. Very frequently, such approaches consider the modularity level and product variety (*e.g.*, Salvador *et al.* 2002). Further studies focus on the impact of product modularity on supply chains (Fine 1998).

The NPD process determines the variety level to be produced. Variety is a multi-dimensional concept that can be divided into external and internal variety. External variety is seen by the customers, whereas internal variety is related to the diversity of components and semi-final products (Pil and Holweg 2004). In addition, variety has a static and dynamic component. Static variety represents a single snapshot of the variety handled by the manufacturing firm whereas dynamic variety reflects the whole picture as variety evolves. Dynamic variety is the product mix that a company creates over time in order to serve the marketplace better. The optimization of business processes for a given static variety without considering the dynamic impacts of new product introductions may have detrimental effects on operations. There is no reason that a supply chain system that is optimal for a given variety stays optimal when the level of variety changes.

4.2.2 Mass Customization

Mass customization is a hybrid business strategy that focuses on the fulfillment of individual customer requirements at high efficiency. Mass customization has proven to be very successful in many industrial environments; it enables companies to improve profits and outpace competitors. These advantages can be achieved, however, only if manufacturing firms can accommodate the changes imposed by the strategy. It is not by applying mass production principles that products can be customized effectively and efficiently. Mass customization induces many changes on operations, reaching from product design over manufacturing and assembly to marketing and sales. Taking into account the main topic of this paper, we only focus on mass customization implications on product design and supply chains.

The implementation of mass customization calls for the application of adequate design rules that minimize product lifecycle costs. Product design for mass customization should address the conflicting goals of reusability and differentiation (Robertson and Ulrich 1998). In this respect three approaches have been recommended so far: commonality, modularity, and platform strategies.

Component commonality (Collier 1981) means that a few components are used on a large number of products. A high level of end variety does not necessarily trigger a high variety of components. A study in the automotive industry shows that external variety and internal variety are uncorrelated (Pil and Holweg 2004).

The development of products around modular architectures is the best way to achieve mass customization (Pine 1993). Modularity has been defined in many different ways in the academic literature. Ulrich (1995) requests a one-to-one mapping between functional requirements and physical components to refer to products as modular. Although this requirement ensures a high level of modularity, the one-to-one relationship is rather the exception than the rule in the real world. Very frequently, product architectures are located on a continuum, reaching from completely integral to perfectly modular designs. Thus modularity is a matter of degree (*e.g.*, Salvador *et al.* 2002); it denotes a multidimensional rather than a one-dimensional property of products (Abdelkafi 2008).

In a mass customization setting, modularity should enable the creation of a large number of product variants by mixing and matching a small number of building blocks. To achieve this, interfaces must be standardized, in such a way that the building blocks are built into many different products. Interfaces "describe in detail how the modules will interact, including how they will fit together, connect, and communicate" (Baldwin and Clark 1997, p. 86). Interfaces are part of the visible design rules, which are shared among the supply chain partners in order to ensure that the product can function as an integrated whole. The hidden design parameters, however, are related to decisions that are restrained to the local design of product modules (Baldwin and Clark 1997). Modules may also be carried over several product generations. That is, the manufacturing firm updates or generates new products by varying a small number of modules, while keeping a subset of modules unchanged over time. In this way, the economies of substitution are likely to be achieved. These economies arise when the costs of designing a better system through the partial retention of existing components are lower than the costs of designing it afresh (Garud and Kumaraswamy 2003).

The third variety management approach to ensure distinctiveness and reusability is product platforms. A platform has been defined differently in the academic literature. Some authors (*e.g.*, Meyer and Lehnerd 1997) refer to platforms as the whole set of modules to derive product variants; others (Piller and Waringer 1999) consider it as the basic module, which is common to an entire product family. The latter definition imposes strong constraints on the product architecture; it not only requests modularity, but also an extreme level of commonality of one or more core modules.

When dealing with variety, however, firms mostly focus on optimizing the static variety, thereby neglecting its dynamic nature. Especially in mass customization, is variety unlikely to be static. Static variety cannot fulfill customer requirements, as tastes and preferences evolve in the course of time. In effect, today's product program does not satisfy future customers' needs.

Beside product design, mass customization imposes several requirements on the upstream and downstream parts of the supply chain. The upstream part deals with the transportation, consolidation and warehousing of materials and components required in production. The downstream part concentrates on the packaging and shipment of end products to customers.

The upstream supply chain should ensure that components and modules are delivered on time according to the production schedule. The downstream supply chain delivers on a *per* item basis, since customized products are directly shipped to the customer. It also can carry out a part of the customization process if customers can choose among different logistics options of packaging and transport. Customized packaging (*e.g.*, gift wrapping) and individual delivery are two options that show how to involve supply chain logistics in the customization process (*e.g.*, Riemer and Totz 2001). A smooth functioning of the upstream and downstream supply chains is highly relevant because poor delivery reliability may make customers doubtful about the benefits of mass customization.

4.3 Aligning NPD and SCM in Mass Customization

Most variety management approaches preferably concentrate on static than dynamic variety. When variety-related problems emerge in the supply chain, the common reaction of firms is to reduce the number of produced variants by changing production plans. Though this action decreases the extent of variety and improves operational efficiency, it does not tackle the problem at its very origin; it is only a reactive measure with a short term reach. As customers' requirements change rapidly, new products have to be introduced more frequently. If the company does not consider the impacts of this new variety on the supply chain, it is very likely that a firm's operational efficiency deteriorates, thus leading the company to react again by reducing the level of variety in order to cut costs.

The mere reaction to a problem cannot be an effective approach to improve efficiency. A proactive approach that anticipates the effects of changing variety is therefore advantageous, as it avoids costs before they are incurred. In other words, the interdependencies between dynamic variety, introduced at the product design phase and supply chain should be examined already at the early phases of product development. By anticipating the effects of the new variety on the available supply chain, the company may adapt the suppliers' network to accommodate this variety better or may decide to not introduce the new products at all. In both cases, the proactive approach seems more powerful than the reactive approach. In fact, research on proactive approaches to align NPD and SCM is still in its infancy. Based on a review of the literature, however, Ellram *et al.* (2007) conclude that there is substantial theoretical evidence that proactive approaches provide beneficial outcomes to organizations.

Dynamic variety has far-reaching impacts and influences the design and configuration of the network of suppliers and distributors. The degradation of the cost structure results not only from variety but also from NPD-SCM misalignment. Putting it simply, the supply chain incurs high costs if the supply chain cannot accommodate the level of variety offered to the customers. Because variety is likely to be very high in a mass customization environment, the alignment issue gains importance. For a given level of variety, two different supply chains can lead to different cost structures. Previous studies also demonstrate that supply chain management decisions can help to mitigate the negative implications of product variety on operational performance. For instance, researchers (*e.g.*, Randall and Ulrich 2001) found that locating suppliers of high variety components next to the target market of end products can reduce inventory costs.

To check the impact of dynamic variety on the supply chain, we conduct a case study. The firm under analysis is the electronics division of a European multinational company in the medium-to-low-voltage electrical appliances sector. The firm is characterized by a high and growing product variety. Recently, it refreshed its product range by introducing a new line that deeply changed the structure of its offer. To collect data, a case study protocol was generated. Interviews were carried out with the supply chain director and manufacturing plant manager. Documentary and data analysis, *e.g.*, the distribution of sales *per* item, comparison of the workloads on the processes involved in the manufacturing of the old and the new product lines were also performed.

The introduction of the new line has resulted in an increase in the number of end products and technologies to be managed both in products and production processes. The new products contained new electronic components and new process technologies. This led to an increase in the relative importance of purchasing over manufacturing, in inter-site dependency for the main plant producing the final products, and the need to look for new purchasing markets.

Despite all of this, the consequences of the introduction of the new line and the change in nature of the firm's catalog on supply chain structure were not at first fully evaluated. The supply chain structure and systems were not adapted to the new situation. As a result, operational performance declined.

Using selected key metrics, we noticed that the supply chain is not capable of transporting and delivering the product variety that the plant can produce. In particular, the quotient of the count of different manufactured items (MC_i) and the count of different demanded items in the ith working week (DC_i) has been computed. This metric is called tracking ratio: $TKR_i = MC_i / DC_i$. The tracking ratio measures supply chain capability of delivering variety compared to the market need for variety. In the firm's context, demand for variety DC_i increased after the introduction of the new line, whereas the weekly manufactured items MC_i were the same as before. Consequently, the supply chain, as designed and managed, was unable to deliver the new variety mix requested by the clients. This gap is due to the misalignment of SCM and product variety originated by the introduction of the new line.

The case study demonstrates the relevance of aligning SCM and product variety in the course of time. A deeper analysis reveals that the roots of the problems are located in a specific aspect of the dynamic variety. Not every modification of the product and in the level of variety must be associated with changes in the supply chain. For instance, if new variety is created by upgrading a module that can be produced and delivered by an old and reliable supplier in the network, the products change, but supply chain does not.

Based on these ideas, we propose to develop a comprehensive NPD-SCM alignment framework for mass customization. As can be seen in the literature review, NPD ascertains four product properties that are relevant to the supply chain: static variety, dynamic variety, modularity, and innovativeness. Academic and practitioner literature has already recognized the relationships between modularity, static variety, and supply chain performances, but it has neglected the impact of product innovativeness and dynamic variety. Our discussion will explain the relationship between dynamic variety and innovativeness and why they should be considered when dealing with NPD-SCM alignment. In the following, the main variables of the NPD-SCM framework and the relationships between them will be discussed.

4.3.1 Innovativeness and Dynamic Variety

Innovativeness is the degree of novelty of an innovation. It can be measured from the viewpoint of an entire industry, a firm (Garcia and Calantone 2002), or the final market (Danneels and Kleinschmidt 2001). Market innovativeness is related to the external variety, which customers can see and perceive. To produce it, the company may need to create internal variety such as new components and/or modules. Though unperceived by customers, internal variety is frequently necessary to enable market innovations. According to Garcia and Calantone (2002), the elements of novelty of an innovation can be looked for in 17 spheres, including technology, product line, process, and product.

Innovations are the output of innovation projects. Different innovation projects come up with different degrees of innovativeness. New concepts are developed within breakthrough projects and lead to completely new products. Architectural innovations involve new platforms or changes in existing product architecture; they are developed within platform projects. Finally, derivative projects give rise to new module or component innovations (Wheelwright and Clark 1992).

When an innovation is introduced, the variety that is managed by the supply chain can change. Dynamic variety accounts for the change in the product mix. Innovativeness measures the magnitude of change introduced by the innovation project in terms of product novelty for the supply chain. In the consumer-electronics industry, we believe that dynamic variety and innovativeness are negatively related, *i.e.*, highly innovative product development projects are associated with low dynamic variety. Because of the combined effects of innovativeness and variety on the supply chain, we do not expect firms to launch highly innovative products in many versions. Firms with high performance offer high variety when the innovativeness degree is low. This hypothesis is very important and should be checked empirically, as it enables one to discover how highly performing supply chains ensure NPD-

SCM alignment. For instance, the "MacBook Air" is an extremely innovative product launched by Apple Inc., however it is sold in two versions only (source: http://store.apple.com). The validation or rejection of this hypothesis needs intensive empirical work and can represent the subject of future work.

4.3.2 Supply Chain Configuration, Collaboration, and Coordination Complexity

SCM studies can be grouped by the decisions they deal with. Supply chain design research (*e.g*., Delfmann and Klaas-Wissing 2007) focuses on the topological features of the logistics network and the level of collaboration among partners in the supply chain. Supply chain planning and execution literature tackles the decisions regarding the methods and tools to use in a supply chain, once it has been built up, in order to achieve efficiency and service level requirements (Simchi-Levi *et al.* 2002). The application of mass customization strategy requires making decisions on the supply chain topological features and collaboration levels, as well as the planning and execution tools. Supply chain characteristics depend on these decisions. To capture the characteristics of the logistics network, the descriptive model by Hieber (2002) can be used.

According to Hieber (2002, pp. 63), a supply chain can be described by three main dimensions: configuration, collaboration, and coordination. Configuration refers to "the modelling of the existing business relationships between the network entities." Collaboration "describes the degree and kind of partnership between the participants"; it deals with the level of mutual trust and openness between the actors and whether or not the network strategies are aligned. Coordination describes "the daily operations of transcorporate processes and methods in the logistic network", *e.g*., the intensity of use of IT tools to support activities, and the autonomy in the planning decisions. A list of measurable complexity drivers is associated to each dimension (Hieber 2002, pp. 63).

Hieber (2002) defined a direction of increasing complexity for the drivers that characterize all three dimensions. For example, the use of integrated systems for planning and execution among partners indicates higher coordination complexity, as compared to the mere fulfillment of orders and delivery. Since each supply chain can be described in terms of Hieber's complexity drivers, the complexity of configuration, collaboration, and coordination can be measured. These metrics can summarize the main features of the supply chain.

4.3.3 Supply Chain Performance

Mass customization aims to provide the market with customized products efficiently. NPD-SCM alignment is fundamental for achieving mass customization objectives. To evaluate NPD-SCM alignment, effectiveness and efficiency performance must be monitored. In particular, the delivered mix of products must be compared to customer orders, and the actual costs must be measured to assure that efficiency targets are achieved. In a mass customization setting, these comparisons allow for assessing, on the one hand, whether the level of customization is actually satisfied, and, on the other, whether the firm is facing operational problems such as overstocks.

4.3.4 Alignment Framework and Propositions

NPD-SCM alignment depends on the right choice of supply chain features, given the product characteristics. These choices should aim to achieve mass customization objectives. We develop a NPD-SCM framework that shows the relationships between product and supply chain characteristics. The arrows in the framework designate direct effects of one variable on another but no indirect effects, as these can be deduced logically. For instance, if variable 1 affects variable 2, which in turn has an impact on variable 3, then the indirect effect of 1 on 3 is obvious. In order to avoid redundant information this type of relationship will not be not represented in the framework. An arrow from 1 to 3 should be drawn only if the first variable directly affects the third one in some way (Figure 4.1).

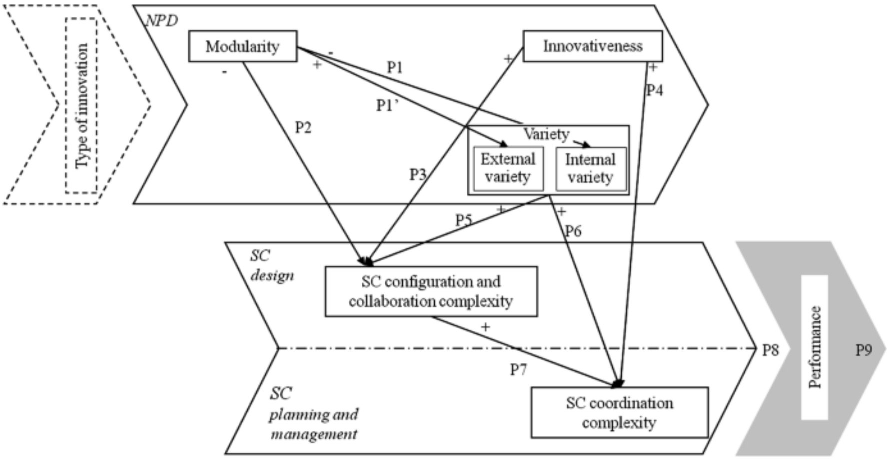

Figure 4.1 The NPD-SCM framework

4.3.4.1 Modularity

Modularity is fundamental in a mass customization setting. It increases external variety because it enables companies to mix and match modules into different end products and reduces costs due to the economies of scale and scope. When a new product with a modular architecture is introduced, the number of end variants (dynamic variety) is likely to increase. Modularity, however, has a negative effect on internal variety. A large number of end variants can be produced by using a few modules (internal variants).

Proposition 1a (P1a): Modularity increases the level of external variety offered to the customers.
Proposition 1b (P1b): Modularity reduces the level of internal variety handled by the manufacturing firm.

The module interfaces make it possible for module suppliers to work independently (Fine 1998 Sturgeon 2002). Ro *et al.* (2007) show that in response to product modularization, leading car producers reduced their supplier base. Module suppliers now assemble entire product modules and coordinate large component sourcing networks (Doran *et al.* 2007). From the viewpoint of the firm, which sells the end product under its brand name (*e.g.*, original equipment manufacturer, OEM), the complexity of supply chain configuration is reduced. To assure high quality and reliable delivery, OEMs should develop trust-based buyer–supplier relationships with their module suppliers, while aligning their strategies (Sako and Helper 1998). That reduces collaboration complexity from the OEM's viewpoint. Consequently, we can state the following proposition:

Proposition 2 (P2): Modularity reduces the level of configuration and collaboration complexity.

4.3.4.2 Innovativeness

According to the case study presented above, supply chain decisions are not only based on product modularity; the degree of novelty of the introduced product should also be taken into account. Platform projects, an example for highly innovative projects, call for deep changes in product architectures and may lead firms to work with new suppliers or even to in-source some production activities. In both cases, supply chain complexity increases. The multiple case study research by Caridi *et al.* (2008) shows that highly innovative NPD projects result in a higher increase in supply chain configuration, collaboration, and coordination complexity than less innovative NPD projects. Therefore, we state the following:

Proposition 3 (P3): Innovativeness increases supply chain configuration and collaboration complexity.
Proposition 4 (P4): Innovativeness increases the level of supply chain coordination complexity.

Innovativeness measures the magnitude of the novelty from the viewpoint of the firm that introduces the innovation. Therefore, if two firms A and B introduce a new product with the same variety level, but with different degrees of modularity and innovativeness, our framework expects different changes in the features of supply chains A and B. Figure 4.2 depicts the relative magnitude of the changes of supply chain configuration and collaboration in different scenarios, depending on modularity and innovativeness.

Let us look in-depth into studies dealing with the effects of product modularity on supply chains under the light of the framework. At a first glance, contradictory results can be seen. Doran *et al.* (2007) noticed that modularity led to higher collaboration with suppliers in the automotive industry, whereas Fine (1998) observed the opposite in the electronics industry. This contradiction can be resolved, however, if we take innovativeness into account.

The comparison between the automotive and electronics industry provides an explanation. Doran *et al.* (2007) focus on the trend towards modularization that is visible in the car industry. The most popular example of this trend is the Smart car. From the viewpoint of the car manufacturer, it is a platform innovation. Fine (1998), however, describes an industry where products are highly modular and the interfaces between modules are stable and well-defined (*e.g.*, Fine 1998; Sturgeon 2002). In this industry, innovation rather leads to derivative products. Single suppliers develop and manage innovations without interfering with others. Thus the change in supply chain configuration and collaboration is not too strong when a new product is introduced. Only with the introduction of a new standard (high innovativeness level), can a bigger change in the supply chain occur. In the automotive industry, however, car manufacturers should collaborate intensively with their suppliers to produce innovations and to react to modularization trends. Figure 4.3 shows the positions of both industries in the previous matrix.

Modularity	Higher	*lower effect*	*Medium effect*
	Lower	*medium effect*	*higher effect*
		Low	High
		Innovativeness	

Figure 4.2 Expected effects on supply chain complexity depending on modularity and innovativeness

Modularity	Higher	*Electronics industry*	
	Lower		*Automotive industry*
		Low	High
		Innovativeness	

Figure 4.3 The actual relative effects described in the electronics and automotive industries

4.3.4.3 Variety

Variety is widely recognized to increase SCM complexity. For instance, variety leads to a loss in scale economies because volumes are split among more products.

High variety firms experience higher demand uncertainty and forecast errors than low variety firms (Abdelkafi 2008, Pil and Holweg 2004, Da Silveira 1998).

A multiple case study research conducted by Tachizawa and Thomsen (2007) in different industries highlights that firms use flexible sourcing strategies with a larger supply base, a lower level of supplier integration, and faster supply network re-design in low commonality, high demand volatility, and high volume and mix uncertainty contexts. It should be noted that Tachizawa and Thomsen (2007) disregard product modularity and innovativeness. Given the same replenishment lead time, the proliferation of end items increases the levels of stock. To reduce inventory costs, the best performing firms in the US bicycle industry locate suppliers of high variety components next to the target market, thus increasing responsiveness to demand. However, the manufacturing of components whose production costs are high is centralized (Randall and Ulrich 2001). Therefore, supply chain configuration complexity increases. The supply chain coordination tools required to manage a high variety environment are more complex. Kaipia and Holmström (2007) propose differentiated planning approaches for firms with a large product portfolio, as this kind of firm face more intricate supply chain planning problems.

Proposition 5 (P5): Variety increases the complexity level of supply chain configuration and collaboration.
Proposition 6 (P6): Variety increases the complexity level of supply chain coordination.

Abdelkafi (2008) analyzes variety-induced complexity in mass customization and studies the complexity reduction potential of different variety management strategies. The introduction of an innovation in the form of a new product line can result in additional variety, and so additional variety-induced complexity. This may negatively impact the effectiveness of the variety management strategies, which aim to increase supply chain performance. It is expected that the complexity of a mass customization system will be less sensitive to variety if this variety moves under a certain limit level. Blecker and Abdelkafi (2006) believe that after going beyond this limit complexity will increase exponentially, leading to a system that is unpredictable and difficult to manage. This thesis boosts the importance of anticipating the effects of dynamic variety on the supply chain.

4.3.4.4 Supply Chain Complexity and Performance

The tools for planning and operatively managing the supply chain should be chosen on the basis of supply chain design decisions. For instance, information sharing tools should be used to integrate clients and suppliers (Hill and Scudder 2002).

Proposition 7 (P7): Supply chain configuration and collaboration complexity increase the level of supply chain coordination complexity.

The HP case study shows that in order to fully exploit the potential of postponement strategy to achieve mass customization benefits, the position of the order penetration point and the modularity of the product should be concurrently defined (Feitzinger and Lee 1997). In the automotive industry, the empirical work by Jacobs *et al.* (2007) shows that modularity affects supply chain efficiency and flexibility. This impact is mediated by supplier integration, *i.e.*, supplier development, JIT purchasing, and the level of partnership. The empirical survey by Selldin and Olhager (2007) shows that at the supply chain level, the alignment of the product and supply chain design is significant for supply chain responsiveness, delivery dependability, and supply chain efficiency. Salvador *et al.* (2002) notice that the right combination of product modularity, product variety, and sourcing strategy (related to supply chain design) enhances operational performance.

On the basis of these considerations, the following can be stated:

Proposition 8 (P8): Supply chain performance depends on supply chain design decisions, and product modularity, product variety and innovativeness.
Proposition 9 (P9): By matching product modularity, product variety, innovativeness to supply chain design planning and management, the supply chain performance is enhanced.

4.4 Conclusions

This chapter presents a framework for NPD-SCM alignment that can be applied in a mass customization context. It suggests that the matching of supply chain configuration, collaboration, and coordination with product features supports firms that want to offer customized products at high efficiency and responsiveness. The alignment framework includes modularity, dynamic variety, and innovativeness. We believe that the optimization of business processes for a given static variety without considering the dynamic impacts of new product introductions negatively affects operations. Indeed, a supply chain system that is optimal for a given variety does not necessarily stay optimal when the level of variety changes and when a highly innovative product is introduced. A case study supports this idea. Key metrics have been used to evaluate dynamic variety and its impacts on supply chain operations.

We analyze the relationships between supply chain-related variables and product features and then formulate propositions. Propositions are based on theoretical argumentation and the comparison of published case studies. We show that the consideration of innovativeness and dynamic variety can justify decisions that contradict the managerial guidelines recommended by modularity research in mass customization. Further research should be devoted to the validation of propositions and better understanding of the dynamics of NPD-SCM alignment in mass customization settings.

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