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A framework for the alignment of new product development and supply chains

Margherita Pero, Nizar Abdelkafi, Andrea Sianesi, Thorsten Blecker,

Research paper

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Margherita Pero
Department of Management, Economics and Industrial Engineering, Politecnico di Milano, Milano, Italy

Nizar Abdelkafi
Institute of Business Logistics and General Management, Hamburg University of Technology, Hamburg, Germany

Andrea Sianesi
Department of Management, Economics and Industrial Engineering, Politecnico di Milano, Milano, Italy, and

Thorsten Blecker
Institute of Business Logistics and General Management, Hamburg University of Technology, Hamburg, Germany

Abstract

Purpose – The purpose of this paper is to develop a framework that explains how new product development and supply chain variables are related to one another and how they affect performance.

Design/methodology/approach – The insights from literature and an exploratory case study are combined to develop an alignment framework, which is then tested using a multiple case study design.

Findings – Variety, modularity, and innovativeness are the product features that are taken into account when studying alignment. From the supply chain viewpoint, configuration, collaboration, and coordination complexities are the variables that matter. Innovativeness is found to have a stronger effect than variety on supply chain complexity. In addition, there is evidence that matching product features with supply chains improves performance.

Originality/value – The paper provides empirical support to the relationships among the variables within the alignment framework. There is evidence that product innovativeness, a variable so far neglected in the alignment literature, can have a critical impact on the supply chain. Furthermore, supply chain complexity must be adequately adapted, depending on the product features.

Keywords Supply chain management, Product development, Case studies

Paper type Research paper

1. Introduction

Many research works have investigated the relationships between product design and supply chain (e.g. Fisher, 1997; Randall and Ulrich, 2001). Understanding this relationship is important because of two main reasons. First, the design phase creates the products to be manufactured and distributed within the supply chain, thus determining a large portion of supply chain costs. Second, the magnitude of the effects of product design on the supply chain depends on the adequate choice of supply chain practices, such as the outsourcing concept, supply chain structure, positioning of the production sites and warehouses (Blackhurts *et al.*, 2005), and supply chain strategy (Childerhouse *et al.*, 2002). In other words, for a given product design, a particular supply chain practice leads to a better operational performance than another.

Manufacturing firms must continuously update their product offers in order to satisfy customers' requirements better, while staying competitive. Because of the increased rate of product introductions, managers should adapt the supply chain characteristics more frequently to deliver the new products effectively and efficiently. The supply chain must be aligned with product development decisions; it should be designed and managed, so that the products are delivered at the targeted cost, time, and quality. Alignment of new product development (NPD) with supply chain management (SCM) should allow the manufacturing firm to overcome problems such as (partially) failed product launches due to the lack of product availability because of insufficient capacities (Van Hoek and Chapman, 2007). NPD-SCM alignment leverages supply chain capability, enhances the effectiveness of new product introductions and improves firm's performance (Van Hoek and Chapman, 2006). It is also one of the basic elements of a successful marketing strategy (Christopher and Peck, 1997; Christopher *et al.*, 2004).

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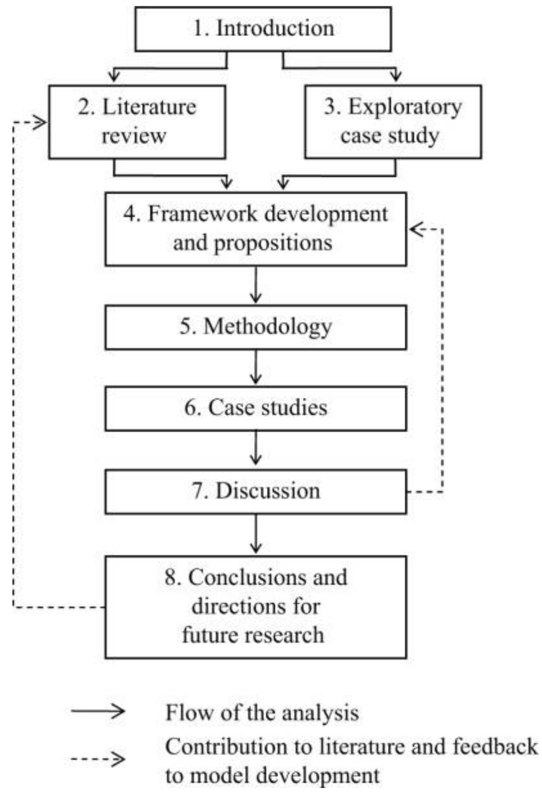
So far, however, there is no comprehensive framework dealing with NPD-SCM alignment. Management practice needs a tool that explains the impacts of introducing new products on the supply chain. Depending on product features, the tool should provide guidance to managers and enable them to identify the supply chain decisions that lead to high performance. Therefore, we can formulate two research questions:

1 How do NPD and SCM variables relate to each other?
2 How can companies, in practice, align NPD and SCM, in order to achieve high supply chain performance?

To answer the research questions, we proceed as follows. First, we analyze the literature dealing with NPD-SCM interdependencies and conduct an in-depth exploratory case study. This case study, conducted at an early stage of the research process, improved our understanding of how new products affect the supply chain. Second, we combine the findings from the literature and the case study to develop the alignment framework and to formulate nine propositions indicating the relationships between NPD and SCM variables. Finally, the framework is applied to five case studies representing different industrial settings. The objective is to check the extent to which the theoretical propositions can be supported or not. Because we are basically investigating the question of how (Yin, 1994) supply chain practices and performance change after introducing a new product, case study methodology is the most suitable research strategy.

The remainder of the paper is organized in line with the research methodology. The next section discusses literature on NPD-SCM alignment. Section 3 presents the findings from the exploratory case study. Section 4 introduces the framework and describes the relationships between NPD and SCM variables in terms of propositions. Section 5 describes the methodology used to validate the framework whereas section 6 applies the framework to five industrial case studies. Section 7 discusses the propositions with respect to the case study findings. Finally, the last section concludes, derives some managerial implications and presents a few directions for future research (Figure 1).

Figure 1 Research procedure



2. Literature review

NPD and SCM are the main areas of analysis. 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; Wheelwright and Clark, 1992). It uses a plethora of methods to assess and integrate customer needs into product design (Ulrich and Eppinger, 2000), along with tools from project management and concurrent engineering (Swink, 1998).

SCM and NPD are related to each other since the supply chain produces and distributes the product, which is the output of the development process. SCM is the approach to designing, organizing, and executing all the activities from planning to distribution along the entire value chain, including the network of suppliers, manufacturers and distributors (Childerhouse *et al.*, 2002; Vonderembse *et al.*, 2006). Most SCM models and methods, however, assume that product design decisions have been already taken (Simchi-Levi *et al.*, 2002). Recently, an increasing emphasis on the coordination of SCM and NPD can be noticed (Hult and Swan, 2003; Rungtusanatham and Forza, 2005). The approaches that tackle this issue are either NPD-oriented or SCM-oriented (Table I).

The NPD-oriented approach anticipates the supply chain constraints at the early stages of product development. This approach may be called "design for supply chain management" (Lee and Sasser, 1995). Decision support models of the NPD-oriented approach either consider bill-of-materials (BOM) or product architectures. First, the relevant costs, e.g. transportation and inventory costs in the supply chain, are expressed as a function of the product structure representation (i.e. BOM, General-BOM, or Planning BOM). Then, the cost function is optimized, in order to find the best product structure for a given supply chain (Blackhurts *et al.*, 2005; Huang *et al.* 2005; Lee and Sasser, 1995). Researchers, however, use product architecture-based models more frequently. Product architecture is "the scheme by which the function of the product is allocated to physical components" (Ulrich, 1995). 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, 2001); other models focus on postponement and the placement of the differentiation point in the supply chain (Feitzinger and Lee, 1997).

SCM-oriented literature considers that the product and its characteristics are given. Two model types are available in this regard. The first type defines supply chain strategy (lean, agile, or hybrid) depending on product- and market-related

Table I The main approaches and main variables highlighted in literature

Approach to NPD-SCM alignment study		Supply chain-related variable	Product-related variable	Literature references
NPD-oriented	Proactive	SC structure SC costs	Architecture BOM	Lee and Sasser (1995); Huang *et al.* (2005); Blackhurts *et al.* (2005); Novak and Eppinger (2001); Feitzinger and Lee (1997)
SCM-oriented	Reactive	SC strategy definition	Product innovativeness	Childerhouse *et al.* (2002); Vonderembse *et al.* (2006); Fisher (1997)
		SC structure Operations SC costs Buyer-supplier relationship	Modularity Variety	Salvador *et al.* (2002); Fine (1995); Sturgeon (2002); Doran *et al.* (2007); Ro *et al.* (2007); Lau and Yam (2005); Fisher and Ittner (1999); MacDuffie *et al.* (1996); Miller and Vollmann (1985); Brun *et al.* (2006)

variables such as demand variability, variety level, and demand volumes (Vonderembse *et al.*, 2006; Christopher *et al.*, 2004; Huang *et al.*, 2002; Fisher, 1997). The second type investigates how supply chain design is impacted by the product structure. Very frequently, these models consider the level of modularity and roduct variety (Salvador *et al.* 2002). Further studies examine the effects of product modularity on intra-firm and inter-firm organizations, in relationship to product design (Sanchez and Mahoney, 1996), and organizational structure (Schilling and Steensma, 2001). The basic assumption of these studies is that modular products lead to modular organizations. An organization is called modular when it consists of a loosely coupled network of organizational units that can be flexibly recombined into many configurations. Design modularity implies that the design teams work autonomously on independent physical modules. The modularity concept can also be extended to supply chains. Fine (1995) argues that an increase in product modularity increases supply chain modularity. Nevertheless, the definition of modularity in supply chains is still fuzzy, and there is no consensus on it. An empirical research by Hoetker (2006) shows that the question whether modular products lead to modular organizations is rather simplistic. Organizational modularity is a more complex phenomenon than it is thought to be.

Because a common definition of supply chain modularity is missing, we only look at the implications of product modularity on the supply chain. Product modularity facilitates the concentration on core competencies, and the outsourcing of less strategic activities to suppliers. Modularity also triggers a re-definition of the role of the first-tier suppliers (Doran *et al.*, 2007; Ro *et al.*, 2007; Doran, 2004), who can produce entire modules and systems (Gadde and Jellbo, 2002), while coordinating the network of component suppliers. Product modularity and interface standardization enable a reallocation of tasks, in a way that the brand name firm conducts the development process whereas the contract manufacturer carries out production (Sturgeon, 2002). Modularity can also lead to extensive co-development efforts between the OEM and suppliers to define the product architecture (Lau and Yam, 2005). Once it is defined, module suppliers make the detailed module development (Ro *et al.*, 2007).

Product modularity is also closely related to the level of variety that the company can develop and produce. Variety decisions are mainly taken within the NPD process and have big impacts on the operational performance of the supply chain. The relationship between variety and supply chain has been studied with respect to direct manufacturing costs and overheads, delivery times, inventory levels, changes in the purchasing and production plans (Holmström *et al.*, 2006; Fisher and Ittner, 1999; MacDuffie *et al.*, 1996; Miller and Vollmann, 1985), and behavioral costs, "those costs which arise because of the reaction of people to 'excessive' variety" (Brun *et al.*, 2006).

Recapitulating, literature considers variety and modularity to be the main outputs of product development with an impact on the supply chain. With respect to the supply chain, the variables studied so far are more concerned with strategic aspects, in particular the design of the suppliers' network, and the intensity of collaboration among supply chain partners.

3. Exploratory case study

The following case study has been conducted in order to explore the NPD-SCM alignment in an industrial setting.. The extended version of the case study is presented in Crippa *et al.* (2008). The firm under analysis (called DS in the following) is the Electronics Division of ELETECH Group, a European multinational company in the medium-to-low-voltage electrical appliances sector. With more than 2.000 products generating a yearly turnover of around €150 million, the company's offer spans over major domotics systems, fully integrated in style and compatible with the rest of ELETECH catalogue (more than 60,000 products). Being one of the most innovative firms in its sector, the firm enlarged its product offer in 2005. First, it introduced a new top-level, stylish product family, and second it changed the nature of its offer, moving from "stand-alone" devices to integrated systems. These changes increased the number of products and called for new production technologies that have not been used before by the company.

Most products are highly integrated; in other words the level of product modularity is low. The products are *de facto* components of a system and therefore must be all marketed with high service level standards. The unavailability of a single product may heavily impact overall service level. Most problems are in part due to the product offer extension that was accompanied by the introduction of a significant amount of low-volume items. A Pareto analysis, conducted on 2006 cumulative sales, shows that instead of the expected 50 percent on products count, the C-class items represent more than 2/3 of the catalogue. The introduction of the new line also results in an increase in the number of technologies to be managed in products and production processes within the main plant. Moreover, the new products contain new electronic components and new process technologies, leading to an increase in the relative importance of purchasing over manufacturing, in inter-site dependency for the main plant, and the need to enter in new purchasing markets.

The effects of the new line introduction and changes in the catalogue on the supply chain were not fully understood. Consequently, the supply chain structure and practices were not adapted to the new situation. This led to a loss of performance, which was measured against increased difficulties in keeping high service level, (both line item fill rate and percentage on average weekly gross requirements); against master planning (MPS) accuracy, which fluctuated around an average of 75 percent, and against an MRPII standard target of 95 percent. The weekly analysis of unavailable items evidenced that the cause of poor service level is due to the difficulties in fulfilling the demanded mix. This has been measured by the Tracking Ratio $TKR_i = MC_i/DC_i$, which evaluates the supply chain's capability of delivering the demanded variety ($i = i^{th}$ working week; MC_i = count of different items manufactured in i^{th} week; DC_i = count of different items demanded in i^{th} week). Accordingly, TKR can be considered a way of measuring operations flexibility *vis-à-vis* market variety needs. The higher the TKR, the higher is the capability of delivering variety. The application of this indicator in the case study shows that after the introduction of the new line, DC_i increased, whereas MC_i is almost the same. This means that the supply chain, as designed, is not able to keep pace with the variety the client requests.

4. NPD-SCM alignment framework

The case study makes it obvious that other variables, in addition to those identified by the literature analysis, have to be taken into account to match NPD with SCM decisions. Product variety and modularity are not the only variables that matter when investigating the impacts of NPD on the supply chain. The product line newness level (or degree of innovativeness), a factor controlled during product development, can have considerable impacts on the supply chain. In addition, not only strategic issues such as supply chain design can be affected by new product introductions, but also the supply chain operations issues, which are tightly related to the daily business. Figure 2 depicts the alignment framework, which will be discussed in-depth in the following sections.

4.1 New product development variables

The academic literature has already recognized the effects of modularity and variety on supply chain performance, but did not consider the impacts of product innovativeness. In total, the alignment framework includes three NPD variables: modularity, product variety and innovativeness.

4.1.1 Modularity

So far, several definitions of modularity have been provided (Fixson, 2007; Gersehnson *et al.*, 2003; Salvador, 2007). Modularity is a system characteristic (Schilling, 2000). Modular systems consist of loosely coupled modules (Sanchez and Mahoney, 1996; Schilling, 2000) that can be mixed and matched (Schilling, 2000) by the use of standardized interfaces (Baldwin and Clark, 1997; Sanchez and Mahoney, 1996). The interactions between modules are minimized whereas the components inside the module are strongly coupled (Gersehnson *et al.*, 2003).

The higher the level of modularity, the more development and production tasks can be done independently and simultaneously. Furthermore, the level of product modularity impacts the degree to which the supply chain is modular. To measure modularity, Abdelkafi (2008) proposes three different metrics: the level of coupling between modules, the degree of correspondence between the product functional elements and physical components, and the degree to which a few module variants can generate many product variants.

4.1.2 Product variety

Like modularity, product variety has been studied and defined from different perspectives. Fisher *et al.* (1999) underline its static and dynamic nature and classify product variety according to two dimensions: the breadth of the product range at a given time and the rate at which the firm replaces the existing products. Pil and Holweg (2004) distinguish between external and internal variety. Whereas external variety denotes the level of choice to the customers, internal variety is experienced inside manufacturing and internal supply chain operations. The level of internal variety can be measured through commonality metrics (e.g. Collier, 1981) whereas the level of external variety can be evaluated by the absolute number of product variants. External variety need not necessarily imply a high level of internal variety, as companies offering a wide product range may exhibit high component commonality.

4.1.3 Innovativeness

Garcia and Calantone (2002) refer to innovativeness as the degree of newness of an innovation from the viewpoint of an entire industry or a firm. Danneels and Kleinschmidt (2001) consider innovativeness from the customer's and firm's viewpoints. This classification is, in fact, rooted in the work by Booz, Allen & Hamilton Inc. (1982), who divide innovations according to the level of innovativeness for the market and the company. In the present work, we only consider the firm and its supply chain.

With respect to the level of newness, Garcia and Calantone (2002) identify 17 features; among others: technology, product line, process, and product. Because this research focuses on new products, the measure of "what is new" should be related to the product itself. Many indicators have been proposed for measuring product innovativeness from the firm's viewpoint, and most of them are of qualitative nature (Table II).

The level of innovation depends on the type of the innovation project. Wheelwright and Clark (1992) define three kinds of new product projects: breakthrough projects, platform projects, and derivative projects. Breakthrough projects require the highest level of investments and come up with completely new products. Platform projects aim to develop architectural innovations, whereas derivative projects give rise to new module or component innovations. Needless to say, architectural modifications exhibit a higher innovation level than module innovations.

4.2 Supply chain variables

4.2.1 Supply chain configuration, collaboration, and coordination

Supply chains are generally investigated with respect to supply chain design and supply chain planning and management. Supply chain design ascertains the topological features of the

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Figure 2 Detailed framework

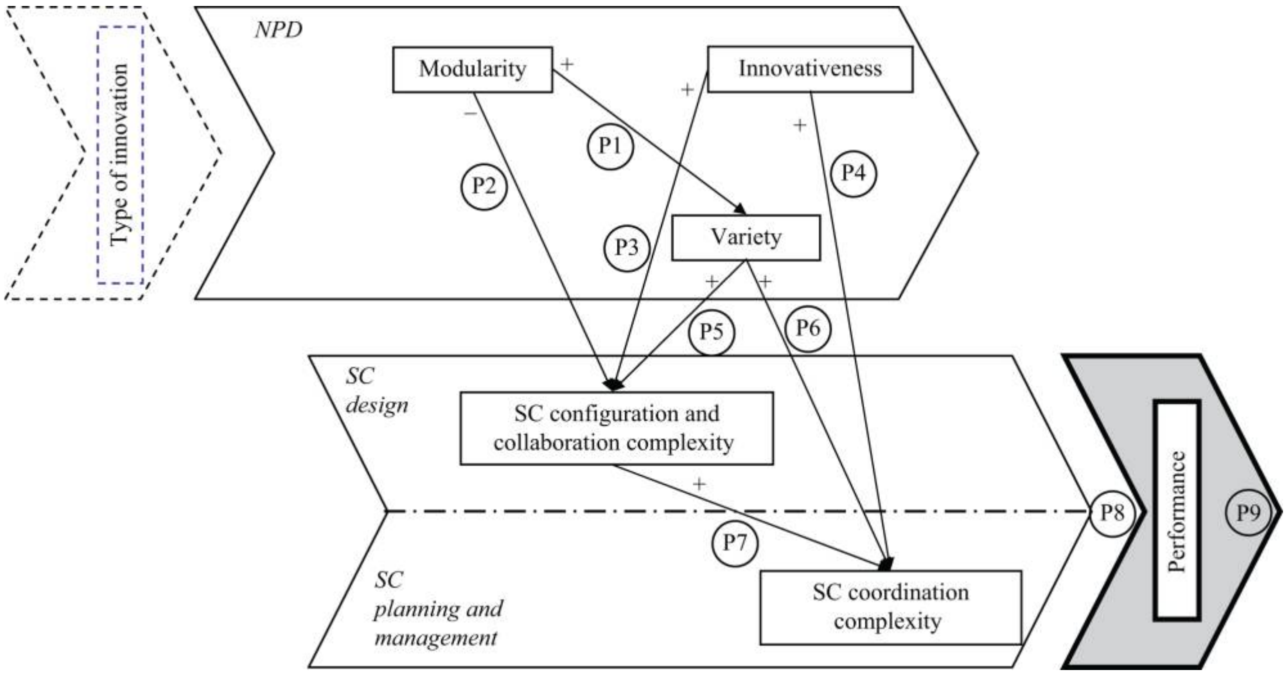

Table II Indicators for measuring product innovativeness

Article	Area	Innovativeness = Degree of ...	Scale
Henderson and Clark (1990)	Product	... changes in the linkage between concepts and components and/or changes in the core concepts	Four cells in a matrix: (1) Incremental innovation, (2) Modular innovation, (3) Architectural innovation, (4) Radical innovation
Clark and Fujimoto (1991)	Product	... internal newness (with respect to internal already known components) and/or external newness (with respect to competitors)	1-3 qualitative from incremental to radical
	Production process	... internal newness (with respect to internal already known processes)	1-3 qualitative from incremental to radical
Wheelwright and Clark (1992)	Product	... change in the product	Four steps: new core product, next generation product, addition to product family, derivatives and enhancement
	Production process	... change in the process	Four steps: new core product, next generation product, little department upgrade, incremental change
Mishra *et al.* (1996)	Product	... newness of customers for products ... newness of product class ... newness of customer needs ... newness of production process ... newness of technology ... newness of distribution ... newness of advertisements	For each dimension 1-10 qualitative variables
Schmidt and Calantone (1998)	Product	... newness for the customer and/or newness for the design, manufacturing and marketing department in the firm	Innovative new products: new or very unique solutions to users and new design, manufacturing and marketing challenges to firms Incremental new products: incremental advantages, marginal changes to design

network and the level of collaboration between partners, whereas supply chain planning and management make use of specific tools to operate the designed network.

Hieber (2002) develops a descriptive supply chain model with three main dimensions: configuration, collaboration, and coordination. The configuration dimension refers to "the modeling of the existing business relationships between the network entities." The collaboration dimension "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 the network strategies are aligned or not. The coordination dimension 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 (Hieber, 2002).

For each dimension, Hieber (2002) proposes a list of measurable drivers and, for each driver, a scale of increasing complexity. For example, the geographical spread of the network is a configuration driver that has four values, listed in order of increasing complexity: local, regional, national, and global. Hieber (2002) also defines the complexity drivers of collaboration and coordination. For instance, 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. Thus, Hieber's complexity drivers can be used to capture the characteristics of the supply chain network.

4.2.2 Supply chain performance and delivered variety

The alignment of SCM and NPD should lead to an improvement in the supply chain performance, which can be measured in many different ways (Caplice and Sheffi, 1994). In particular, performance is tightly linked to the concept of delivered variety. Delivered variety refers to the number of different products a company actually delivers to the market and must be defined in relationship to efficiency and responsiveness. If the delivered variety does not keep pace with the customers' orders, then the firm is facing operational problems such as backlogs, stock-outs or overstocks. If it matches, then performance is expected to be high.

4.3 Relationships among the variables

Modularity has been widely recognized as a concept that enables variety production, while avoiding the negative impacts on operational performance and achieving better economies of scale and scope (Pine, 1998). Modularity makes it possible to create end product variety by mixing and matching modules:

P1. Modularity increases the level of variety offered to the customers.

Modularity enables firms to decrease the level of vertical integration by relocating value-added activities, while reducing the size of suppliers' base. The assembly of entire product modules is the responsibility of a fewer first-tier suppliers (Ro *et al.*, 2007) who coordinate a large component sourcing network (Doran *et al.*, 2007). Thanks to modularity, the focal firm experiences a lower supply chain configuration complexity. Consequently, we can formulate the following proposition:

P2. Modularity reduces the level of supply chain configuration complexity.

Similarly, the complexity of collaboration between the focal firm and its first-tier suppliers is expected to decrease because modularity assumes the specification of clear visible design rules (Baldwin and Clark, 1997), with well-defined module interfaces. Module suppliers can work independently on module development, once the interfaces have been collaboratively defined (Fine, 1995; Sturgeon, 2002). To tackle the remaining complexity in collaboration, supply chains should improve trust and strategy alignment of buyer-supplier relationships (Hieber, 2002; Sako and Helper, 1998):

P3. Modularity reduces the level of supply chain collaboration complexity.

Nevertheless, some authors mention that modularity induces a higher collaboration complexity (e.g. Doran *et al.*, 2007; Ro *et al.*, 2007), especially at the design stage. One explanation why contradictory results emerge in this regard is that researchers are studying different industrial contexts. For instance, Doran *et al.* (2007) observed that modularity increases collaboration complexity in the automotive industry, and Fine (1995) noticed the opposite effect in the electronics industry. But modularity is a matter of degree that can vary from an industrial setting to another. Logically, industries with higher levels of modularity exhibit lower levels of complexity. In addition, product innovativeness is an important factor that influences the level of collaboration between the supply chain partners. In the electronics sector, the interfaces between modules are standardized because products are highly modular (e.g. Fine, 1995; Sturgeon, 2002). Innovations are developed and managed by single suppliers without interfering with others, and this does not lead to a strong change in supply chain configuration and collaboration. Only with the introduction of a new standard, a bigger change in the supply chain can occur. In the automotive industry, however, car manufacturers should collaborate intensively with their suppliers to produce innovations because of the high interconnections between modules.

Generally, highly innovative products call for deep changes in product architectures. For firms, this may lead to working with new suppliers, or even to producing new parts internally. In both cases, the supply chain complexity of the focal firm increases. The empirical results by Caridi *et al.* (2008) show that an increase in the innovativeness of the NPD projects results in higher complexity due to the changes in supply chain configuration, collaboration and coordination:

P4. Innovativeness increases the level of supply chain configuration and collaboration complexity.

P5. Innovativeness increases the level of supply chain coordination complexity.

Whereas modularity reduces complexity, variety drives the opposite effect. Product variety increases production and purchasing costs and leads to a loss in scale economies because volumes are split among more products (e.g. Abdelkafi, 2008; Sciuccati and Capello, 1999). Furthermore, product variety intensifies demand uncertainty and forecast errors (Pil and Holweg, 2004). Given the same replenishment lead time, inventories increase in the level of product variety (Randall and Ulrich, 2001). This makes supply chain coordination more difficult, and the firm needs more sophisticated and complex planning tools. Kaipia and Holmström (2007) propose differentiated planning approaches for firms with large product portfolio, as this kind of firms face more intricate supply chain planning problems. In terms of supply chain configuration, Tachizawa and Thomsen (2007) find that low component commonality, high demand volatility, and high volume and mix uncertainty drive firms to use flexible sourcing strategies with a larger supply base, lower level of supplier integration, and faster supply network re-design. Though these results draw on multiple case studies in different sectors, they disregard product modularity and innovativeness. Randall and Ulrich (2001) performed a study in the US bicycle industry to outline the effect of product variety. They show that the need to reduce inventory costs leads the best performing firms in the industry to locate suppliers of high variety components next to the target market, thus responding quicker to demand. However, the manufacturing of components whose production costs are high is centralized:

P6. Variety increases the level of supply chain configuration, collaboration, and coordination complexity.

The choice of the tools for planning and managing the supply chain is related to configuration and collaboration. For instance, it is advisable to use practices and tools such as VMI (Vendor-Managed Inventory) or information sharing to achieve a higher level of collaboration and integration between client and suppliers (Hill and Scudder, 2002):

P7. Supply chain configuration and collaboration complexity increases the level of supply chain coordination complexity.

Though related, the three types of supply chain complexity are more strongly dependent on product characteristics. With the introduction of a new product line, complexity can remain constant or increases, but does not decrease. The adjustment of the supply chain, by increasing its complexity, is necessary to maintain a high performance level. This is in line with complexity research (e.g. Beer, 1966), which shows that in order for systems, in general, to achieve their goals while coping with the changes in their environment, there must be an increase in internal complexity. Thus, from a performance viewpoint, the adaptation of the supply chain is necessary. Fisher (1997) observes that supply chain strategy (efficient vs responsive) should be defined according to the product type (functional vs innovative). Selldin and Olhager (2007) give empirical support to Fisher's model, showing that the alignment of the product with network design is significant for delivery speed, delivery dependability, and cost performance. Salvador *et al.* (2002) find that the right combination of product modularity, product variety and sourcing strategy (related to supply chain design) leads to enhancing operational performance. The empirical work by Jacobs *et al.* (2007) shows that modularity affects automotive supply chain performance in terms of costs efficiency and flexibility. This impact is mediated by supplier integration, which depends on supplier development, JIT purchasing and the level of partnership. Consequently, we can state the following propositions:

P8. Supply chain performance depends on supply chain design decisions, and product modularity, product variety and innovativeness.

P9. By matching product modularity, product variety, and innovativeness with supply chain design planning and management, the supply chain performance is enhanced.

5. Methodology

In order to check the validity of the propositions, the case study methodology seems most suitable. According to Yin (1994), case studies are adequate for dealing with the "how" questions, especially in research studies where it is impossible to separate the phenomenon from its context. We are interested in investigating how supply chains adapt after launching new products. To achieve this goal, we have to capture the changes in supply chain practices, and compare them to the initial situation before new products are introduced. In-depth interviews and on-site observations provide a more powerful methodology than other techniques such as large-scale surveys to explore this transitional phase of supply chains.

To provide an empirical support for the alignment framework, we conduct five analytical case studies in firms of different sizes operating in different industries. It is noteworthy that the case study presented in section 3 is exploratory, since it aims to investigate a new phenomenon; the insights gained from this study are used to develop the framework. The analytical case studies, however, are suitable to provide evidence and test already defined research propositions. Furthermore, confirmatory multiple case study analysis enables one to make generalizations.

A heterogeneous sample is chosen to explore different practices, using the supply chain as the unit of analysis. Every case study represents a supply chain, which adapted its operations to accommodate a recently introduced product line. Data are collected by means of interviews and company-specific documents. The interviews have been carried out with supply chain managers, logistics, NPD and/or purchasing directors. Interviews with more than one actor served to capture different points-of-view and also to triangulate the data, thus increasing the reliability of the information obtained from the respondents. Wherever applicable, firms' databases were used to gather additional data, and direct visits to plants and warehouses served to make on-site observations. The use of the multiple case-study methodology and the analysis from the perspectives of different actors on the same topic, support the generalization issue. Table III summarizes the main characteristics of the sample and the tools used for data collection.

A study protocol to conduct the research has been defined. In particular, the interview guideline consists of questions capturing the characteristics of the new product in terms of its modularity, innovativeness, and variety. By analyzing the product structure, we could classify the new product as either modular or integral. The degree of innovativeness was assessed against the type of the innovation project, as defined by Wheelwright and Clark (1992). The level of variety was evaluated by analyzing the increase in the number of the new products (or product lines) with respect to the complete firm's catalogue.

Other questions in the interview guideline are formulated to explore the changes in supply chain management practices due to the launch of new products. Changes in the level of supply chain complexities were estimated by evaluating the changes occurred in all the descriptive drivers presented in Hieber (2002). Hieber's model was used as coding scheme for systematically converting the qualitative data (interviews) into quantified variables. In particular, the values of each

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Table III Sample features

	Company A	Company B	Company C	Company D	
	Case study 1	**Case study 2**	**Case study 3**	**Case study 4**	**Case study 5**
Industry	Electrical motors and alternators	Solenoid valves	Apparel	Weapon	
Revenues (2008)	€170M	€20M	>€1,000M	€157M	
New product introduced	New alternator for automotive sector	New production process and new solenoid valves	New concept for children's clothes	New gun for self-defence	New rifle for sport
Interviewed manager(s)	Supply chain and logistics directors	Purchasing director	Supply chain and logistics director, NPD manager	Supply chain and logistics directors	
Tools	Direct interviews	Direct interviews and firms' databases analysis	Direct interviews, direct observation, firms' databases analysis	Direct interviews	

complexity drivers have been defined precisely by means of key words, examples and definitions. Within-case study analysis has been performed by writing a detailed case study description and abstracts of relevant interview segments (Eisenhardt, 1989). These have been scanned and analyzed under the lenses of the Hieber's driver values' definitions. In line with the methodology of Thornborrow and Brown (2009), this analysis has been conducted jointly with researchers who did not participate in data collection, and we were sensitive in examining rigorously materials in order to avoid bias. This allows for performing more reliable cross-case comparisons. The measured changes in Hieber's drivers enable us to estimate the tendency of change in the supply chain complexity dimensions.

Finally, performance has been measured against efficiency and responsiveness. More specifically, efficiency was evaluated by comparing the target and actual costs that the firm incurred after introducing the new product. Responsiveness corresponds to the degree actual service levels matched with target service levels (e.g. measured against on-time deliveries). Thus, misalignment cases are defined as supply chains that are unable to achieve the target performance after launching a new product.

6. Case studies

Company A is a first tier supplier producing alternator stators for the automotive industry. It is vertically integrated and manages a small network of raw material suppliers. Recently, a new line of alternators exhibiting an integral architecture and low variety was introduced. This innovation led to a limited extension of the suppliers' network, and gave rise to new production lines. In order to ensure compatible solutions for the car manufacturer, company A now collaborates more intensively with other automotive suppliers.

Company B, a worldwide major electro-valve producer, introduced a new production system, incorporating a highly innovative technology. However, no big changes were introduced in the product itself. This resulted in several new product lines and led the company to enlarge its global supplier base, while strengthening its relationships with existing suppliers and involving them in the development phase. Moreover, quality control, previously under the responsibility of clients, shifted to the company. Company B could reduce production lead time and stock levels.

Company C is a worldwide leading company in the apparel industry. It manages a complex network of textile plants, production sites, logistics hubs and platforms, etc. Although garments are integral products, end variety is high because of different designs, textile types, sizes, colors, and brands. A recently innovative product line for children, inducing a large dynamic variety every month, has been launched. Whereas the concept is promising from a commercial viewpoint, it induced many problems in the downstream supply chain. This led to a degradation of operational performance and poor service levels.

Company D is a vertically integrated weapons' producer, working with around 80 suppliers. Recently, the company introduced two modular, high variety product lines characterized by different innovativeness levels. The first product involved an architectural innovation, whereas the second only a minor change to an existing product line. Interestingly, both products induced an increase in the number of suppliers. The more innovative product necessitated special-purpose parts, whereas the less innovative product required the company to look for additional production capacities to overcome the increase in demand of some standard modules. For both product lines, supply chain performance is high.

Table IV recapitulates the case studies and shows the tendency how the variables within the NPD-SCM alignment framework change after the introduction of the new products.

7. Discussion

To discuss the propositions, we organize them into four groups. We study *P1* separately because it is the only proposition that connects two product design variables (variety and modularity). *P2* to *P6* relate product design to supply chain variables and are therefore discussed together. *P7* focuses on the relationship between the supply chain variables and is dedicated a further subsection. The last subsection examines propositions *P8* and *P9*, which deal with

Table IV Summary of the case studies results

	Company A	Company B	Company C	Company D	
	Case study 1	Case study 2	Case study 3	Case study 4	Case study 5
Variety	−	+	+	+	+
Modularity	−	−	−	+	+
Innovativeness	+	−	+/−	− (but higher than case 5)	−
Configuration complexity	↑	↑	=	=	↑
Collaboration complexity	↑	↑	=	↑	=
Coordination complexity	↑	=	=	↑	↑
Supply chain performance	+	+	−	+	+

Notes: + High; +/− Middle; − Low; ↑ Highly increased; ↑ Increased; = Did not increase

performance and alignment issues. The results of this discussion are summarized in Table V.

7.1 Discussion of proposition P1

A cross-comparison among the case studies shows that modularity and variety are not usually positively correlated. The supply chains in the second and third cases created high variety, though products are not modular. Because the supply chain in the second case is performing well, it follows that modularity is not a necessary condition to operate an efficient supply chain with high variety.

7.2 Discussion of propositions P2 to P6

The cross-comparison of case studies 2, 4 and 5, which represent supply chains producing high variety, shows that for a given level of innovativeness, there is no evidence that modularity reduces the complexity of the network structure. Consequently, proposition *P2*, which foresees a decrease in configuration complexity as modularity increases, is not supported. There is, however, evidence that modularity is capable of reducing collaboration complexity, thus supporting *P3*.

Case studies 2 and 3 provide some support for propositions *P4* and *P5*; the cases make it obvious that, for a given level of variety (high), an increase in the level of innovativeness that is not followed by a rising supply chain complexity results in a misalignment situation because performance degrades. For instance, the introduction of an innovation at company B, which is an alignment case, drove the firm to expand its suppliers' base by involving global and culturally different actors, and to strengthen co-design and partnership relationships with traditional suppliers. In the misalignment case (company C), however, the supply chain was rigid and did not adapt to new products. One of our interview partners illustrates the unwillingness to change the supply chain structure, as he noted:

> We have never called into question the way we have been working till now. These [the supply chain planning, order cycle, supply chain network . . .] are "dogma" that we assume are right.

The analysis of case studies 1, 2 and 3 enable one to detect the effects of innovativeness and variety, given a specific level of modularity (low). In the first and second cases, which are opposite regarding their innovativeness and variety levels, supply chain configuration complexity has increased after launching the new product. Nevertheless, innovativeness seems to have a higher impact on complexity than variety. The same conclusion can be done for coordination complexity. But innovativeness and variety have almost comparable impacts on collaboration complexity. To illustrate the impact of innovativeness on complexity, the supply chain and logistics director of company A states:

> The innovation has been developed for a specific client XY. Then it has been adapted for a client of XY. The level of integration with XY has increased.

Table V Propositions discussion

Proposition	Degree of evidence
P1: Modularity increases the level of variety offered to the customer	Partially supported
P2: Modularity reduces the level of supply chain configuration complexity	Not supported
P3: Modularity reduces the level of supply chain collaboration complexity	Supported
P4: Innovativeness increases the level of supply chain collaboration and configuration complexity	Supported – Innovativeness has a stronger effect than variety on supply chain configuration complexity
P5: Innovativeness increases the level of supply chain coordination complexity	Supported – Innovativeness has a stronger effect than variety on supply chain coordination complexity
P6: Variety increases the level of supply chain configuration, collaboration and coordination complexity	Partially supported
P7: Supply chain configuration and collaboration complexity and supply chain coordination complexity	Partially supported
P8: Supply chain performance depends on the matching between NPD and supply chain design	Supported
P9: Supply chain performance depends on the matching between NPD and supply chain planning and management	Supported

> Before, we had just regular meetings. Now we share production plans, and common standards have been defined for the quality control process.

The effects of variety on supply chain complexity cannot be isolated properly. Using the available case studies, the impacts of variety on supply chain configuration and collaboration cannot be detected. Case studies 4 and 5, however, show that variety may increase coordination complexity. In effect, company D introduced low innovative and highly modular products that are offered in a large number of variants. As a consequence, the resulting supply chains experienced a considerable increase in coordination complexity.

7.3 Discussion of proposition P7

Supply chain configuration and collaboration may increase coordination complexity. This illustrates the impacts of strategic supply chain decisions on operations and day-to-day business. There is, however, no observable pattern how this occurs. Whereas in the first case study, a higher coordination complexity is associated with an increased collaboration complexity; in the fourth and fifth case studies, configuration complexity seems to be responsible for the increased level of coordination complexity.

7.4 Discussion of propositions P8 and P9

In total, we investigated four alignment case studies and one misalignment case. The companies in the alignment studies have adapted their supply chains in such a way to cope with the effects of the new product introduction. In the misalignment example (the third case study), this was not the case. Company C is a garment producer. Garments have the property to be intrinsically integral. Although integral product architectures do not facilitate variety creation, company C offers many designs, colors, styles, sizes, etc. To align NPD and SCM, therefore, there must be an increase in supply chain complexity in order to deal effectively with this variety. Company C, however, produces, distributes, and delivers the new product (with a middle level of innovativeness) using the existing supply chain structure and practices. Evidently, this corresponds to an underfilling of Ashby's law of requisite variety stating that "variety destroys variety" (Ashby, 1956). In other words, the supply chain is not complex enough to accommodate the additional variety. This represents, in fact, the major reason explaining why supply chain performance is poor. Recapitulating, we can state that propositions *P8* and *P9* are supported. Note, however, that we cannot assert causal relationships linking product design and supply chain variables with performance, as other variables, not considered in this study, may confound the results.

8. Conclusions and directions for future research

Our research study provides some insights into how companies should design their products, in order to increase the chances of achieving alignment. It is worth noting that the worst case corresponds to the situation when the supply chain receives "no support" from product design, in other words, innovativeness and variety are high, and modularity is low. Such a case is the most difficult to manage because no design variable has a moderating impact on supply chain complexity. By examining the alignment case studies, we can notice that such a case is not available. The companies in the study did not set up all the product design variables at their extreme values. For instance, in the first case study, whereas modularity is low and innovativeness is high, product variety is kept at a reasonable level. In case studies 2, 4, and 5, variety is very high, but innovativeness is relatively low, and modularity is sometimes low, sometimes high. We may conclude, therefore, that firms striving for an NPD-SCM alignment should never set the values of all product design variables at the levels calling for the highest supply chain complexity. If the product is highly modular, high levels of variety and innovativeness can be tolerated. If the product has an integral architecture and the product is highly innovative, it may be necessary to sacrifice variety. These conclusions, however, need to be supported by further case studies.

In theory, modularity reconciles the conflicting goals of achieving a lower level of vertical integration (since entire modules are outsourced), and managing a smaller base of suppliers (lower configuration complexity). Our analysis shows that modularity does not necessarily reduce configuration complexity. The automotive suppliers (companies A and B) produce modules for the original equipment manufacturer (OEM), but their products are not modular and they have to manage a complex network of suppliers. Modularity decreases configuration complexity from the point of view of the original equipment manufacturer (OEM) but not from the suppliers' viewpoint. The pyramid structure of the supplier network (Wildemann, 1998) does not recur downstream the supply chain; in other words, the OEM's module suppliers themselves do not manage a network of module suppliers. It can be concluded, therefore, that the extent to which modularity reduces supply chain configuration complexity, depends on the company's position in the supply chain network.

A possible explanation why configuration complexity increases in spite of modular products is that the designed modules are not outsourced, but produced internally, and that the components required for module assembly are bought from a large base of suppliers. In accordance with our results, Hoetker (2006) found that "product modularity did not help firms in moving activities out of hierarchy." The question is therefore: what makes companies produce their modules internally, although modularity enables outsourcing and complexity reduction? Our research findings suggest that supply chain design not only depends on modularity but also on the level of product innovativeness. Supply chain complexity should be adjusted according to the degree of innovation embedded into the product. Managers should take both variables into account before deciding whether module production should be allocated to suppliers. The important effect of innovativeness on supply chains is also supported by the analysis of the Polaroid case study (Garud and Munir, 2008). In the mid-1960s, Polaroid started to work on a revolutionary camera, the SX-70. The new product required the development and production of a new battery type to be included into the film package. Polaroid developed the specifications of the battery and, in line with the ideas on modularity, outsourced the development and production of the new module to a supplier. But the result was not successful because both parts of the module (battery and film) unexpectedly interacted, as the supplier failed to manage the new technology adequately. Because the innovativeness factor was not considered, the project resulted in higher complexity than expected. Polaroid was forced to in-source battery production and to build a new manufacturing facility, but it was too late, and the project failed.

In general, the transaction costs theory (Williamson, 1975) and the studies on the client-supplier relationships (Ellram, 1990) provide guidance to the firms on how to define the right level of vertical integration and the degree of collaboration with their suppliers. In the make-or-buy choice, the costs of developing new suppliers for the new product should be evaluated against the costs of producing it internally. Our field investigation shows that the low variety-high innovativeness and high variety-low innovativeness cases have both high impacts on supply chain configuration and collaboration complexity. Innovativeness can even have stronger effects on complexity than product variety. Therefore, managers should account for the complexity costs that innovativeness induces in the supply chain.

To achieve alignment, firms may not only match product features with the supply chain, but also long term (supply chain configuration and collaboration) and short term decisions (supply chain coordination). This is what we call: internal alignment. The study by Ro *et al.* (2007) provides evidence to internal misalignment in the US automotive industry. Car manufacturers are only outsourcing module design and production without working on building strong relationships with their suppliers. They still coordinate their business with their suppliers on a cost-oriented basis as negotiations mainly aim at price reductions. Because of this, the US auto supply chains could not reap the supply chain benefits of modularity (Ro *et al.*, 2007). The need of internal alignment is, however, only partially supported by the case study analysis. The validation or falsification of this proposition needs more investigative work in the future. But managers should keep in mind that since modularity decreases collaboration complexity, the failure to exploit this positive effect can lead to misalignment and poor performance.

Finally, it is important to note that misalignment may be due to an over-engineering or under-engineering of the supply chain. In the event that supply chains are over-engineered, highly innovative products may not lead to any adaptations because the supply chain structure is over-dimensioned and redundant. In fact, the product could have been effectively produced and delivered within a less complex supply chain. Because over-engineering incurs higher costs, it represents a misalignment case.

In addition to the insights we could gain from this research, this study raises many questions that can serve as directions for future research. The first question, worth investigating, concerns the product features and their impacts of alignment. In order for a firm to achieve alignment, is it actually helpful not to set up all product design variables at their extreme values? Another question, worth examining, is related to the impacts of variety on the supply chain network. In our analysis, we could not isolate the effects of variety on supply chain configuration and collaboration. Designing multiple case studies with different levels of product variety can help answer this question. Finally, is it possible to provide stronger evidence that the performance of supply chains strongly depends on NPD-SCM alignment? To draw such a conclusion, an adequate choice of misalignment case studies is required. In this work, we have only one misalignment case study, and this is obviously a small number. Especially supply chains that were aligned in the past but could not achieve a good performance after introducing new products are very interesting to investigate.

In addition, a large-scale empirical research could be carried out to find statistical support to the framework. Given the nature of the variables, it may be done in a specific industry in order to have comparable measures of the product features. In the large-scale study, performance can be measured more precisely, thus enabling one to rank the different levels of alignment. In this way, the effects of different pair product features-SCM choices on performance could be detected. Furthermore, it is possible to determine what best-in-class supply chains do with respect to NPD-SCM alignment issues.

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About the authors

Margherita Pero is a PhD candidate at Politecnico di Milano, Italy, dealing with New Product Development and Supply Chain Management Alignment. She is a junior lecturer on the courses of "Operations and supply chain management" at Bachelor level and "Production plants design and management" and "Sourcing and purchasing" at the Master's of Science degree level. In June 2004 she got her Master's Degree with honours in Production and Management Engineering at Politecnico di Milano. Margherita Pero is the corresponding author and can be contacted at: margherita.pero@polimi.it

Nizar Abdelkafi is a research associate at the Institute of Business Logistics and General Management. He holds an industrial engineering diploma from the National Engineering School of Tunis, Tunisia, and a Master's degree in Business Administration from the Technische Universität München, Germany. He got his doctoral degree in 2008 with excellence.

Nizar Abdelkafi has published his work in two books, several conference proceedings and international journals such as: *Electronic Markets, International Journal of Mass Customization*, *Management Decision*, and *IEEE Transactions on Engineering Management*. He also serves as a reviewer for many international journals.

Andrea Sianesi is a full professor with tenure at Politecnico di Milano, Italy. He teaches the course "Operations and supply chain management" at the Bachelor degree level and the course "Production plants design and management" at the Master of Science degree level. He also teaches supply chain management both in the MBA and Executive MBA courses at MIP, the Business School of the Politecnico di Milano. His research topics mainly are: manufacturing and supply chain strategies, innovative models for industrial production management, supply chain management, production systems design and automation. In these areas he has published five books and over 60 papers on international journals and conference proceedings and has participated in a high number of international and national research projects.

Thorsten Blecker is a full professor at the Institute for Business Logistics and General Management. He holds a Master degree in business administration (with honours) and a PhD (*summa cum laude*) from the University of Duisburg, Germany. He finished his habilitation thesis in September 2004 at the University of Klagenfurt, Austria. Thorsten Blecker is co-editor and author of several books, e.g. *Production/Operation Management in Virtual Organizations*, *Enterprise without Boundaries*, *Competitive Strategies*, *Web-Based Manufacturing* and *Information and Management Systems for Product Customization*. Main research interests are business logistics and supply chain management, production/operations management, industrial information systems, internet-based production systems, mass customization manufacturing systems, strategic management, and virtual organizations.

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