2013

Exploring the Development Chain – An inquiry into the linkages between new product development and supply chain management

Dirk J. Primus

BENTLEY
UNIVERSITY

Bentley University: PhD Final Defense Form

This is to certify that we have examined this copy of a doctoral dissertation by

Dirk J. Primus

and have found that it is complete and satisfactory and that any and all revisions required by the final examining committee have been made

Committee Chair:

Signature____________________

Euthemia Stavrulaki

Committee Member:

Signature____________________

Dominique Haughton

Committee Member:

Signature____________________

Markus Fitza

External Reviewer:

Signature____________________

Gloria Barczak

Date: 5-7-2013

Exploring the Development Chain – An inquiry into the linkages between new product development and supply chain management

Dirk J. Primus

A dissertation
submitted in partial fulfillment of the
requirements for the degree of

PhD in Business

2013

Program Authorized to Offer Degree:
Bentley PhD program in Business

ProQuest LLC.
789 East Eisenhower Parkway
P.O. Box 1346
Ann Arbor, MI 48106 - 1346

In presenting this dissertation in partial fulfillment of the requirements for the doctoral degree at Bentley University, I agree that the Library shall make its copies freely available for inspection. I further agree that extensive copying of the dissertation is allowable only for scholarly purposes, consistent with "fair use" as prescribed in the U.S. Copyright Law. Requests for copying or reproduction of this dissertation may be referred to ProQuest Information and Learning Author Relations Team at (800) 521-0600 ext. 7020, to whom the author has granted "the right to reproduce and sell (a) copies of the manuscript in microform and /or (b) printed copies of the manuscript made from microform."

Signature ____________________

Date 07 MAY 2013

DEDICATION

To Alyzee, Audrey and Anja

ACKNOWLEDGEMENTS

The author wishes to express sincere appreciations to the PhD program at Bentley University, the Department of Management and especially to Professor Euthemia Stavrulaki for her vast reserve of patience, knowledge, wisdom and attention to detail. I would also like to express my gratitude to the members of my committee, Gloria Barczak, Dominique Haughton and Markus Fitza. Further, I would like to thank Sam Woolford for his patience and his suggestions with respect to processing and interpretation of the empirical data. Naturally, this dissertation would never have been completed without the encouragement and devotion of my family and friends.

Abstract

Exploring the Development Chain – An inquiry into the linkages between new product development and supply chain management

This dissertation conducts an inquiry into the linkages between new product development and supply chain management. Simchi Levi, Simchi-Levi and Kaminsky (2008) coined the term "Development Chain" for the area where product development and the supply chain intersect. The first chapter of this research (Chapter 2) contributes to a more thorough understanding of the Development Chain (DC) and its impact on financial success with new products. We expand the term Development Chain and provide precise definitions for its scope and its activities. We develop a conceptual view of the DC at the single product/project level which can be understood and applied by academics and practitioners. Chapter 3 studies the impact of the intensity of linkages between sub-processes of the DC on performance. We conceptualize linkages between sub-processes in Product Development (PD) and the Supply Chain (SC) as key problem-solving enablers and we postulate that more intense or participative linkages improve problem solving as they equate to a higher, more diverse exchange and application of vital problem-solving inputs (ideas, knowledge and information). Using a network perspective, we measure the intensity of linkages at three different levels: (1) at the dyadic level between sub-processes, (2) at the level of interwoven, complex linkages between multiple sub-processes that are problem-solving sites and (3) at the aggregate-level where the two domains connect. We find support that, at the aggregate level, more intense connections is not always better (i.e., does not lead to financial success), confirming the tension between PD productivity and higher levels of problem solving. However, we also empirically detect the presence of 5 critical dyadic linkages and 2 complex problem-solving sites that improve product success. Chapter 4 is concerned with a product centric view of DC linkages and alignment of decisions during product development. We develop a conceptual model and conduct empirical tests on three hypotheses for alignment. We find that alignment between product architecture and sourcing or order fulfillment strategies can raise the probability of product success by 55 and 69 percent, respectively. Additionally, we find that the firm-level product success rate positively correlates with alignment between clock-speed and product architecture.

Dirk J. Primus

Chair of the Supervisory Committee:
Euthemia Stavrulaki
Management Department, Bentley University

Committee Members:
Gloria Barczak, Northeastern University
Dominique Haughton, Bentley University
Markus Fitza, Texas A&M University

Table of Contents:

List of Figures:

List of Tables:

Chapter 1 Executive Summary

In the rapidly changing business environment of the 21st century, successful conversion of new ideas into profitable products has become increasingly important. New products can be a key source of revenue and income, they can improve firm valuation and they can act as a catalyst in organizational renewal, adaptation and diversification (Crawford and Di Benedetto, 2008; Brown and Eisenhardt, 1995; Verona, 1999; Pauwels, Silva-Risso, Srinivasan, Hanssens, 2004; Srinivasan, Pauwels, Silva-Risso, Hanssens, 2009). Thus, new product development is critical to the fidelity of firms and of growing concern for researchers and practitioners (Page and Schirr, 2008). At the same time, a business environment characterized by increased price sensitivity, market fragmentation into niche segments, globalization, an elevated demand for product customization, as well as higher rates of new product introduction makes new product introductions are increasingly challenging (Christensen and Raynor, 2003; Thaler, 2003; Fixson, 2005, p.346; Searcy, 2008). Moreover, when a new product is introduced to the market, the product development effort connects with other critical business processes. For example, the delivery system for the new product needs to be ready to deliver and satisfy customer expectations. There are 3 principal scenarios: (1) a new product displaces an expiring product in an existing supply chain, (2) an existing supply chain expands to deliver the new product, or (3) a new delivery system needs to be created. In either case, not only the creation of the new product itself is important, but also the formation of its delivery system that will facilitate a timely and quality delivery during and after its launch.

Already in 1999, Srivastava, Shervaney and Fahey recognized that the two business domains are not independent from each other and suggest that “exploiting their interdependencies is more likely to lead to marketplace success than focus on just one” (p.169). In fact, resource dependency theory suggests that the two domains need to connect to address critical interdependencies. However, effective linkages between these two domains have not been adequately explored. Based on this important insight, this dissertation conducts an inquiry into the linkages between new product development and supply chain management.

Simchi Levi, Simchi-Levi and Kaminsky (2008) coined the term “Development Chain” for the area where product development and the supply chain intersect. The first chapter of this research (Chapter 2) contributes to a more thorough understanding of the Development Chain (DC) and its impact on financial success with new products. We expand the term Development Chain and provide precise definitions for its scope and its activities. We develop a conceptual view of the DC as the nexus of New Product Development (NPD) and Supply Chain Management (SCM) at the single product/project level which can be understood and applied by academics and practitioners. Specifically, we represent the linkages between NPD and SCM as a network which connects 15 sub-processes that are intertwined with people and explain how this network aids in accomplishing DC objectives which ultimately leads to financial success with new products.

We highlight the specific importance and impact of key contextual variables in the DC that influence product success: product and process complexity and context specific DC objectives. We point out that to be effective, the network of linkages needs to adapt to different contexts. To that end, we show that in order to accomplish adaptation, the network of linkages can be varied along four dimensions, (1) network configuration, (2) strength of linkages, (3) timing and (4) resource load. We identify financial success as a suitable ultimate performance indicator for the DC and connect it to the accomplishment of DC objectives that improve the new product as well as its delivery system simultaneously. In this context, we provide a broader definition of financial success with new products that has a pre-cursor in the effectiveness of the linkages of new products and their supply chains.

Chapter 3 studies the impact of the intensity of linkages between sub-processes of the DC on performance. We conceptualize linkages between sub-processes in Product Development (PD) and the Supply Chain (SC) as key problem-solving enablers and we postulate that more intense or participative linkages improve problem solving as they equate to a higher, more diverse exchange and application of vital problem-solving inputs (ideas, knowledge and information). We also conjecture that effective linkages between PD and the SC contribute to product success because problem-solving performance is an important pre-cursor of financial success with new products. However, more and stronger linkages also correlate with greater resource demand and slower decision-making, thus a tension arises between PD productivity and the benefits of more intense problem solving linkages. To investigate these inferences, we measure the intensity of linkages for the 15 sub-processes of the DC, which allows us to study the connections between PD and the SC at three different levels: (1) at the dyadic level between sub-processes, (2) at the level of interwoven, complex linkages between multiple sub-processes that are problem-solving sites and (3) at the aggregate-level where the two domains connect. Using survey data of new product development projects from a wide range of industries we empirically test the effects of linkages on product success. We find support that, at the aggregate level, more intense connections is not always better (i.e., does not lead to financial success), confirming the tension between PD productivity and higher levels of problem solving. However, we also empirically detect the presence of 5 critical dyadic linkages and 2 complex problem-solving sites that improve product success. Furthermore, we test the impact of the two complex sites on financial success with new products and report that increases in the intensity between linkages that form external and internal problem-solving sites can raise the probability of product success significantly.

Chapter 4 is concerned with a product centric view of DC linkages and alignment of decisions during product development. Prior work on strategic alignment suggests that product and financial performance improves when interdependent decisions align their objectives. Specifically, we examine three PD decisions that relate to the product and its supply chain: (1) product architecture, (2) sourcing strategies and (3) order fulfillment. The chapter develops a conceptual model, which explains how the three decisions interact via the product and how their alignment can be tied to a shared performance indicator that is product success via its pre-cursor, product effectiveness. Based on previous literature, we develop dimensions for each of the three decisions with which alignment can be created by practitioners and assessed by managers or researchers. On aggregate, our model suggests that product effectiveness – and by extension financial success with new products - can be increased through alignment between external factors, product architecture, sourcing strategies and order fulfillment strategies. We conduct empirical tests on three hypotheses for alignment. We find in our sample that alignment between product architecture and sourcing or order fulfillment strategies can raise the probability of product success by 55 and 69 percent, respectively. Additionally, we find that the firm-level product success rate is higher for companies that accomplished alignment between clock-speed and product architecture and significantly different from companies that did not.

References

Brown, S.L.; Eisenhardt, K.M. 1995. Product development: past research, present findings, and future directions. ***Academy of Management Review*** 1995, Vol. 20, No. 2, 343-378.

Christensen, C. M., & Raynor, M. E. 2003. ***The innovator's solution: Creating and sustaining successful growth.*** Boston: Harvard Business School Press.

Crawford, M.; Di Benedetto, A. 2008. ***New products management***. Mc Graw-Hill, New York, NY.

Fixson, S. K. 2005. Product architecture assessment: A tool to link product, process and supply chain decisions. ***Journal of Operations Management***, 23: 345-369.

Page, A.L.; Schirr, G.R. 2008. Growth and development of a body of knowledge: 16 Years of new product development research, 1989–2004. ***Journal of Product Innovation Management***. 2008;25:233–248

Pauwels, K.; Silva-Risso, J.; Srinivasan, S.; Hanssens, D.M. 2004. New products, sales promotions, and firm value: The case of the automobile industry. ***Journal of Marketing***, Vol. 68 (October 2004), 142–156

Searcy, T. 2008. Companies don't compete, supply chains compete. ***http://answernet.wordpress.com/2008/11/24/companies-dont-compete-supply-chains-compete***

Simchi Levi, D.; Simchi-Levi, E.; Kaminski, P. 2008. ***Designing and managing the supply chain***. McGraw-Hill, NY

Srinivasan, S.; Pauwels, K.; Silva-Risso, J.; Hanssens, D.M. 2009. Product innovations, advertising and stock returns. ***Journal of Marketing*** Vol. 73.

Srivastava, R.K., Shervani, T.A. & Fahey, L. 1999. Marketing, business processes, and shareholder value: An organizationally embedded view of marketing activities and the discipline of marketing. ***Journal of Marketing,*** Vol. 63 (Special Issue 1999), 168-179

Thaler, K. 2003. ***Supply chain management: Prozessoptimierungen in der logistischen kette***. Troisdorf, Germany: Fortis im Bildungsverlag EINS.

Verona, G. 1999. A resource-based view of product development. ***Academy of Management Review***, Vol. 24, No. 1 (Jan., 1999), pp. 132-142

Chapter 2 Towards a conceptual model for the Development Chain

2.1. Introduction

Successful development and introduction of new products is understood to be an important determinant of sustained company performance (Ernst, 2002). In high performing firms, almost half of the revenue is derived from new products (Crawford and Di Benedetto, 2008). Most importantly, new products enable firms to establish and maintain competitive advantage that allows them to generate higher profits (Brown and Eisenhardt, 1995; Verona, 1999). In addition, recent studies in the automotive sector indicate that the introduction of new products enhances firm valuation (Pauwels, Silva-Risso, Srinivasan, Hanssens, 2004; Srinivasan, Pauwels, Silva-Risso, Hanssens, 2009). Finally, *product development* (PD) can be leveraged to accomplish organizational renewal, adaption and diversification (Brown and Eisenhardt, 1995).

The introduction of new products connects with several critical processes within a business. We focus on its connection with supply chain processes in this chapter. When a new product is introduced to the market, its delivery system needs to be ready to deliver and satisfy customer expectations. There are 3 principal scenarios: (1) a new product displaces an expiring product in an existing supply chain, (2) an existing supply chain expands to deliver the new product, or (3) a new delivery system needs to be created. In either case, not only the creation of the new product itself is important, but also the formation of its delivery system that will facilitate a timely and quality delivery during and after its launch. Accordingly, a significant amount of prior research has recognized that Supply Chain Management (SCM) is one critical area that needs to connect effectively with New Product Development (NPD) (Srivastava, Shervany and Fahey, 1999; Krishnan and Ulrich, 2001; Hult and Swan, 2003, Rungtusanatham and Forza, 2005; Fixson, 2005; Zacharia and Mentzer, 2007; Simchi-Levi, Simchi-Levi, Kaminski, 2008).

In their book "Designing and Managing the Supply Chain", Simchi Levi et al (2008) coined the term "*Development Chain*" for the area where product development and the supply chain intersect and interact to support new product introductions. The Development Chain (DC) represents the “set of activities that is associated with new product introduction”. The scope of the Development Chain includes “product design, the associated knowledge and capabilities that need to be developed internally”, production plans and a set of decisions, like product architecture, supplier involvement, make or buy, supplier selection and formation of strategic partnerships.

Thus, the notion of a Development Chain is an important concept for the interdisciplinary territory between PD and the SC. However, the original idea and definition only offers a high level view of the Development Chain. As a consequence, there is ample opportunity for work in this area that adds more precision and texture to the concept of the Development Chain. Richer conceptualizations of the DC could benefit managerial decision-making and support (empirical) work of researchers in the area of new product introduction. An important contribution of this chapter in this context is the identification of the dimensions that characterize the linkages between PD and the SC beyond the dichotomy of the presence or absence of a high-level connection. Previous work in PD research suggests that dimensions of linkages between development and other areas, such as intensity and timing, are critical to performance (Wheelwright and Clark, 1992). Likewise, we expect that identification of appropriate dimensions that illuminate important differences of DC linkages will facilitate measurement and comparison of their effects across PD projects, firms and industries. Another contribution is the broadening of the scope of the DC. The original idea for the DC as well as other scholarly work in this area focused on intersections of PD with particular functional areas of the supply chain. In Simchi-Levi et al’s account, the Development Chain intersects mainly with the production sub-process of the supply chain and not so much with the supply side or the distribution side of the supply chain. Other prior work concentrated on the linkages between PD and manufacturing or logistics (Zacharia and Mentzer, 2007; Crawford and Di Bennedetto, 2008), or on external links to suppliers (Tatikonda and Stock, 2003; Petersen et al, 2005) and customers (Von Hippel, 1986; Thomke and Von Hippel, 2002) This state of affairs presents an important constraint, because interdependencies typically exist not only between two particular areas, but across multiple areas of PD and the supply chain (Srivastava, Shervaney and Fahey, 1999; Hult and Swan, 2003).

Another important aspect we consider in this chapter is the role of contextual factors, such as the formulation of context specific DC objectives and the complexity of the new product that may influence the effectiveness of linkages. The role of product complexity has been discussed in PD research (Ernst, 2002; Sosa, Rowles and Eppinger, 2004), but has not been adequately related to the DC. Finally, we provide a better understanding of the performance implications of effective linkages between the two domains. Prior work has recognized that tying the interactions between PD and the SC to a common performance indicator is an important task for research in this area (Hult and Swan, 2003).

Our overall goal with this work is to develop a more elaborate conceptualization of linkages between PD and the SC that includes multiple internal as well as external supply chain links and provides researchers and management practitioners with important instruments for measurement and guidelines for decision-making. In addition, we explore conditions under which product development and supply chains connect effectively to support new product introduction. More specifically, our research examines the following questions:

1) What is the purpose and scope of linkages between PD and the SC?
2) How should the domains of PD and the SC be linked and what are the key dimensions of linkages?
3) What are the situational factors that may change the effectiveness of linkages between PD and the SC?
4) What is an appropriate performance indicator to measure effective linkages between PD and the SC?

With respect to the first question, prior work affords an important insights on what are the major objectives for the interaction between PD and the supply chain (Lambert and Cooper, 2000; Krishnan and Ulrich, 2001; Thomke and Von Hippel, 2002; Thaler, 2003; Tatikonda and Stock, 2003; Petersen, Ragatz and Handfield, 2005; Zacharia and Mentzer, 2007; Simchi-Levi et al, 2008). Based on this prior work, we organize DC objectives in three generic categories (Figure 2.1):

- Create and enable the delivery system
- Inform and enhance product design
- Alignment of a new product and its delivery system

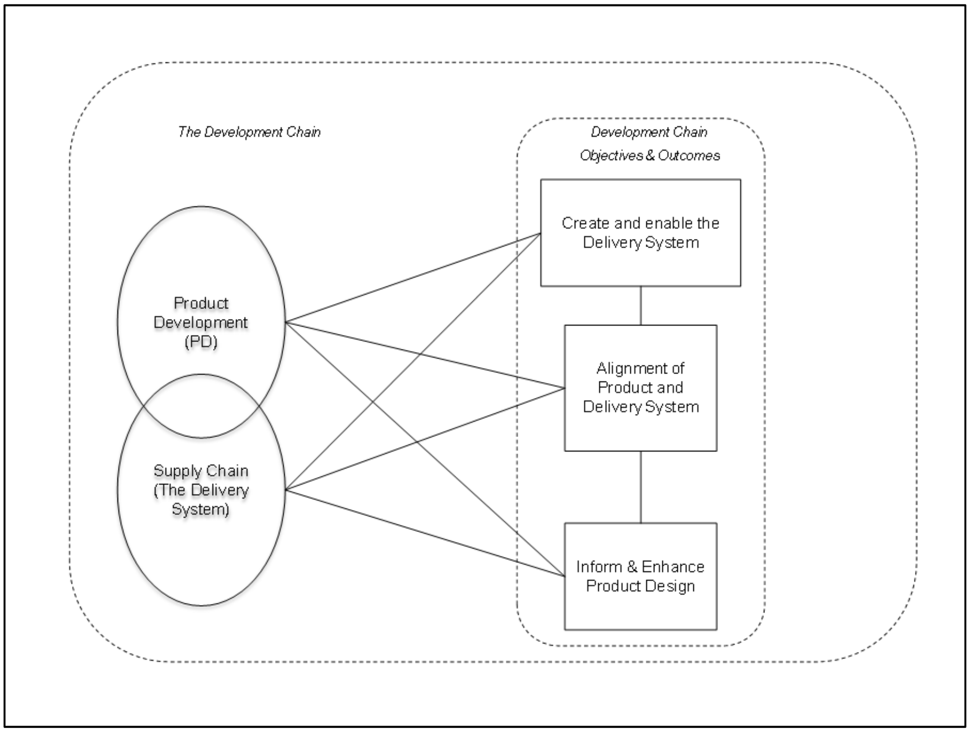


Figure 2.1 The Development Chain and Development Chain Objectives

Although prior research has examined the purpose (objectives) of the DC, the question about the scope of the DC has not been answered precisely. Also, research questions 2) to 4) (about the specific ways to link the two domains, contextual factors that can influence the effectiveness of the linkage and a common performance indicator) have not been adequately addressed. For that purpose, we introduce a conceptual model that is shown in Figure 2.2.

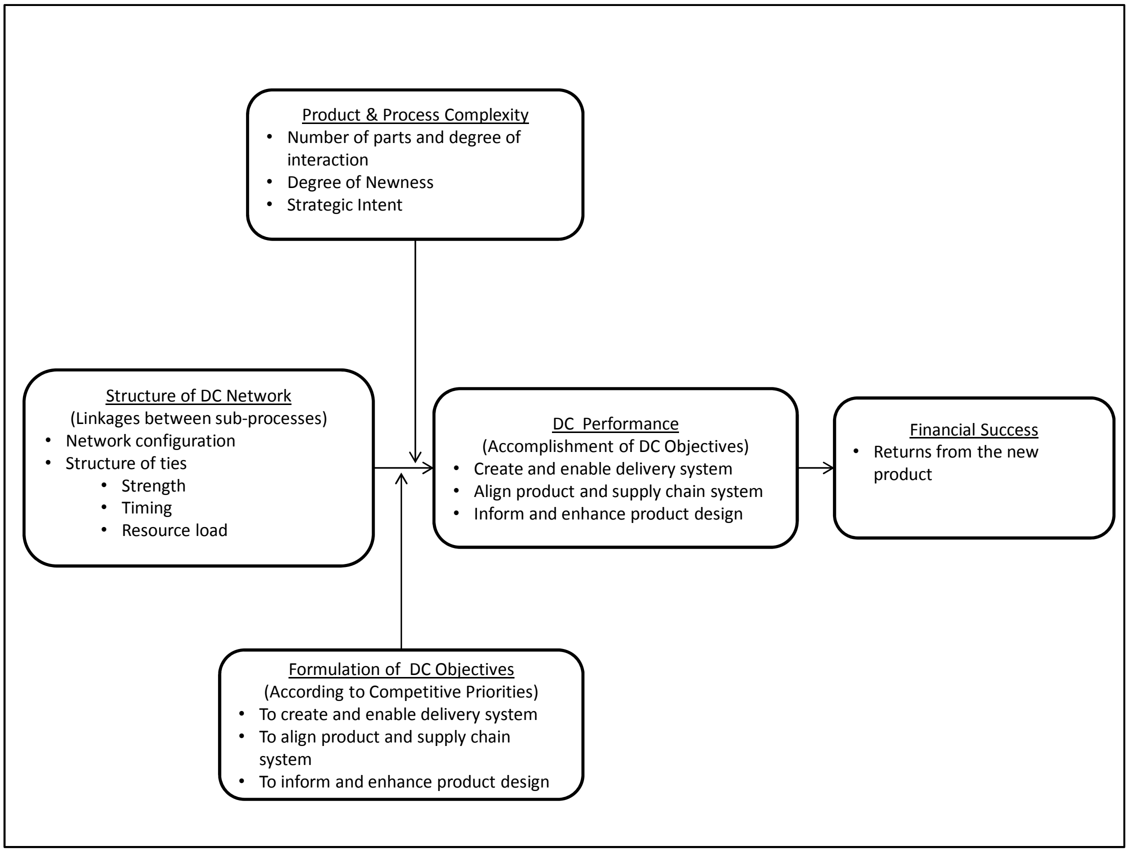


Figure 2.2 **A conceptual model of the Development Chain and its relationship with performance**

Primarily, our model postulates that effective connections between product development and the supply chain can benefit financial success with new products via improvements in Development Chain (DC) performance. In this chapter, we equate DC performance with the accomplishment of DC objectives. Because DC objectives aim at improving the supply chain <u>and</u> the new product simultaneously, an appropriate indicator for DC performance needs to go beyond product development or supply chain performance indicators and comprehensively capture performance of the product as well as its supply chain. In addition, different PD contexts may require different emphases on each of the DC objectives, making it difficult to compare performances across projects, firms and industries. For that reason, we will introduce financial success with new products, measured via return-based indicators, like the *net present value* (NPV). Financial success with new products measured via returns is a consequent of DC performance and represents a suitable performance indicator for the Development Chain for two reasons: (1) Return-based measures, like the NPV, are neutral to context and allow to "evaluate comparable investments in very dissimilar [development] projects"[1] . (2) Financial success, indicated through the NPV can, as we will show in Section 2.7, adequately reflect the performance of the product and its supply chain as a bundle.

Another aspect of the conceptual model in Figure 2.2 relates to contextual variables. We identify two important contextual variables, which moderate the relationship between the DC network of linkages and DC performance: a) formulation of DC objectives and b) product and process complexity. With respect to DC objectives, we will argue that they play a central and a dual role in this chapter. We clearly distinguish between the formulation (strategic vision) and actual accomplishment (performance) of DC objectives, similar to prior work by McKone, Sweet and Lee, 2009. The criticality of the intent/formulation of DC objectives arises mainly because they can be interpreted differently for different products, according to the firm's competitive priorities. Different competitive priorities (such as cost, speed, quality, timeliness or flexibility associated with a new product) may require different linkages between PD and the supply chain. For example, creating and enabling the delivery system for a new product can aim at an efficient supply chain that minimizes cost in one context and a flexible supply chain that maximizes customer value in another. We will thus argue that a) the formulation of DC objectives based on context (context here depends on a number of factors including strategic positioning of the firm, type of industry and type of new product) is an important factor in the formation of effective DC linkages and b) that DC performance is an important antecedent to financial success with new products. We will also highlight the specific importance and impact of product and process complexity as a contextual variable in the DC that influences DC performance. Dimensions of product complexity, such as number of component/parts and degree of newness, have been discussed as a contextual factor in PD and SC research separately, but not in the context of their linkages.

Because there are contextual factors like product and process complexity as well as context specific DC objectives, effective DC linkages need to be adapted to different circumstances. In order to

---

[1] Definition extracted from: The PDMA handbook of New Product Development, 2nd edition, p.595

show how DC linkages can be adapted to different circumstances, we present connections in the DC as a network with primary connections among sub-processes that enable connections between individuals or groups. A network view allows us to highlight how the contextual variables influence DC linkages. We will argue that context specific DC objectives primarily influence which of the network's sub-processes are connected (i.e., the network configuration) while product and process complexity impact how strong (i.e. the communication mode), how early (i.e. timing) and with how many resources should sub-processes be connected.

The structure of the network of DC linkages can vary with respect to specific network configuration, as well as in the structure of its individual linkages in terms of strength, timing and resource load. With respect to the two contextual variables, context specific DC objectives and product complexity, we foresee that the former has its primary impact on network configuration (i.e. 'what' in terms of which sub-processes need to be connected), whereas the latter primarily determines the appropriate structure of ties (i.e. how strong, how early and how many resources) the linkages ought to be.

This chapter proceeds as follows. First, in Section 2.2, we provide a concise definition of the DC, define the scope of our work and connect effective linkages between PD and the SC with DC performance. Next, in Section 2.3 we conceptualize the linkages in the DC at a level where individuals or groups connect through specific sub-processes. Each sub-process has a unique content which requires specific skills, expertise and procedural know-how, which we summarize as intellectual resources. Thus, the different sub-processes in the DC network allow the creation of specific combinations of intellectual resources. We present the four key dimensions of the structure of the network of DC linkages as network configuration, timing, strength of linkages and resource load associated with the processual nodes. In section 2.4, we evaluate the impact of context specific DC objectives and product complexity as contextual variables in the Development Chain. In section 2.5, we present financial success with new products as a suitable performance indicator and show how it can be tied to DC performance. Section 2.6 summarizes our work and concludes with implications on managerial practice and future research.

2.2. The Development Chain

It is clear that any designation of the intersection of product development and the supply chain will flow from the conceptualizations of PD and SC applied. We therefore begin with an overview of our specific views of Product Development and Supply Chains. Supply Chains and Product Development are vast areas and, thus, both can be defined in multiple ways and examined through various different lenses. One particular way to characterize them is through their *structures* and *processes*. This view is popular, because there is little disagreement that structures and processes play an important role in the performance of supply chains and product development alike (Brown and Eisenhardt, 1995; Lambert and Pohlen, 2001; Ernst, 2002).

Supply chains can then be viewed as the combination of *structures* and *processes* by which products reach and satisfy the demand of customers. For example, the dominant structural view of a supply chain is one of a network of cross-functional internal connections (e.g. between buyers, sales and production planners) embedded in external connections with commonly multiple tiers of suppliers and customers (Lambert, 2005). Unlike a specific stream of literature in supply chain management, which focuses on object based networks that include warehouses, vehicles and plants, we concentrate exclusively on networks between people or firms.

Supply chain processes at the strategic and the operational level facilitate the exchange between the nodes of the supply chain network and govern decision-making (Croxton et al, 2001). The performance of the supply network depends on how well the nodes and arcs of the network and the corresponding processes support exchanges of assets (materials, resources, monies), information and knowledge, as well as on how the exchanges are conducted and managed (Croom et al, 2000). When supply chains are characterized in this particular way, the main focus of SCM is on establishing objectives, formulating strategies and making decisions that govern the formation of the network (structure) and the relationships, exchanges and processes throughout the network.

In a similar way, prevalent views of product development include structures and processes by which new products are created (Brown and Eisenhardt, 1995; Ernst, 2002). For example, a central structural concern is the network of participants that contributes to the development of new products. Accordingly, product development performance depends on how diverse internal expertise is aggregated into cross-functional teams (Wheelwright and Clark, 1992) and augmented with external ties to partners, suppliers and customers (Dougherty and Dunne, 2011). A closely related factor is the level of interaction and collaboration that characterizes the relationships between participants of product development (Ernst, 2002, p.15). Although exchanges of assets occur, the primary elements of exchange during product development are information and knowledge.

Views that frame product development in terms of processes organize the creation of new products by actions and content into phases or stages (Crawford and DiBenedetto, 2008; Ulrich and Eppinger, 2011). The key mechanisms that guide and facilitate continued progress with development and managerial assessment through the phases of the project are typically set up in stage-gate models (Hauser, Tellis and Griffin, 2006). The performance of a product development project depends to a significant extent on how well its structure and the processes support exchanges of information and knowledge. Hence, an important aspect of product development is how communication barriers can be overcome with the help of, for example, boundary objects or communities of practice (Dougherty, 1992; Carlile, 2002).

When product development is characterized in this particular way, Product Development Management (PDM) governs the establishment of objectives for development, formation and maintenance of the development network and the processes all of which facilitate the exchanges information of information and knowledge.

Based on the above accounts of supply chains and product development, we adopt a view of the Development Chain, which is about structural and processual linkages between the two domains. Specifically, and as shown in Figure 2.1, we define:

The Development Chain is the union of structures and processes from product development and the supply chain that is required to accomplish objectives which relate to interdependencies between the two domains.

The purview of Development Chain Management (DCM) is to set Development Chain objectives, establish and manage linkages between product development and the supply chain for a new product. Specifically, DCM is concerned with activities from the approval of a product idea for development until the product launch has been completed; in other words, DCM is required for the duration of the development project. It does not include other supply chain activities after a product's launch and during a product's life-cycle, such as inventory management and returns management.

2.3. Scope and unit of analysis

The supply chain and product development are vast areas of research and practice. For example, it is rare for a firm to participate in only one supply chain. Most likely, each of the supply chains has a different structure, different processes and different participants (Lambert and Cooper, 2000). At the same time, it is likely that companies go through several product development and introduction endeavors. It is therefore possible to examine the intersections of PD and the SC at the level of multiple supply chains and multiple products. For example, one could examine how synergies and economies of scale in the supply chain are created by a careful creation of product platforms that leverage the same production processes, parts and components across a range of products & brands (Wheelwright and Clark, 1992). Consider, for example how Volkswagen leverages product platform across its brands Skoda, Seat and, of course, VW.

However, we aim to establish a clear focus on the single project/product level and those areas in the SC and PD that intimately relate to the successful conversion of a product idea to the point where customers can be served and their preferences are satisfied. In other words, our unit of analysis is the development chain for a particular product. As shown in Figure 2.1, we focus on the intersections of the product development activity and the supply chain (delivery system) for a particular product. In the context of this study we use supply chain and delivery system interchangeably.

With respect to supply chain activities, we concentrate on everything that is critical to develop, source, make and deliver a new product (SCOR 9.0; Thaler, 2003; Croxton et al, 2001; Croxton, 2003). Our work is less concerned with customer relationship management (CRM), returns management, as well as data management aspects of supply chain activities (Croxton et al, 2001; Thaler, 2003). Moreover, when we discuss networks of connections, we focus exclusively on how individuals or groups connect through sub-processes in PD and SC. We are not concerned with object based networks that link, for example, production facilities, warehouses and vehicles (Thaler, 2003). Finally, we focus on the key sub-processes of the delivery system for a product that are i) order processing, ii) production planning, iii) procurement, iv) inbound logistics & warehousing, v) production and vi) outbound logistics & distribution (Thaler, 2003; Croxton, 2003), see Figure 2.3.

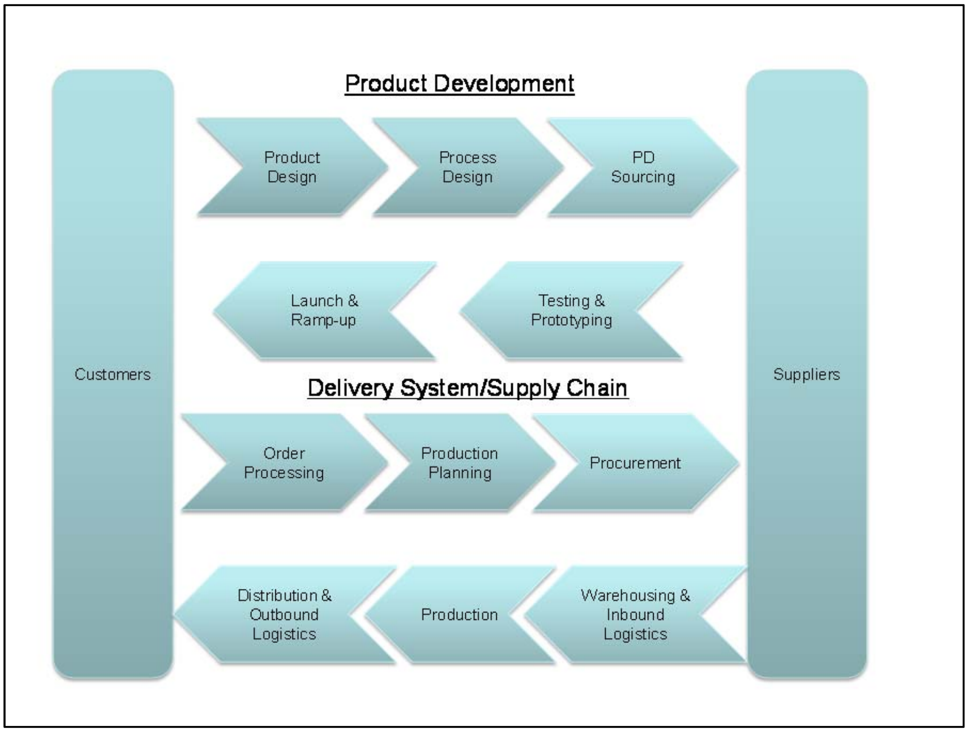


Figure 2.3 Product development and the supply chain for a new product as end-to-end processes that connect customers and suppliers

Similarly, we focus on key new product development sub-processes that include i) product design, ii) process design, iii) PD sourcing, iv) testing & prototyping and v) launch and ramp-up (Krishnan and Ulrich, 2001; Hauser, Tellis and Griffith, 2006; Ulrich and Eppinger, 2011). Hence, our scope for product development focuses on the steps to execute on specific development project. It does not include market research, discovery of technologies or market-opportunities and the evaluation of business cases, which has been circumscribed as "the fuzzy front end" (e.g. P. A. Koen, 2005, in the PDMA handbook, p.83). Accordingly, we consider a narrower scope of product development than the very broad definition proposed by the PDMA.

2.4. Resource Dependency Theory – Interdependencies between PD and the SC

The basic argument of resource dependency theory is that an analysis of the inter- and intra-organizational network can help managers to understand the power and dependence relationships that exist between sub-units within their organizations as well as between their organization and other network actors. The knowledge gained in this analysis affords managers to anticipate the influence of any imbalances between the nodes of the network and the ability to address interdependencies (Hatch, 2006, p.80). Priority in the analysis and ensuing managerial action should be given to actors that control resources which are critical and scarce (Pfeffer and Salancik, 1978).

From the perspective of product development, highest priority should be given to other areas within the company and actors external to the firm who control resources that are critical and scarce to product development. Vice versa, supply chain should give the highest priority to other areas and external actors who control critical and scarce resources. A resource that is critical and scarce to product development and supply chain management alike are domain-specific skills, expertise, procedural knowledge or 'know-how' which we, in accordance with prior research, summarize as *intellectual resources* (Nahapiet and Goshal, 1998; Rungtusanatham, Salvador, Forza and Choi, 2003).

For example, according to Pisano (1996) the primary task of PD is the creation of a product design which serves as a characterization of the new product. The product design "embodies significant information about how the product is manufactured" (Pisano, 1996, p.29). However, "it does not contain explicit instructions for producing large quantities" (Pisano, 1996, p.29), procuring inputs economically and for distributing the new product efficiently. For that reason, product development efforts require additional "expertise about packaging, sourcing, manufacturing engineering or any other relevant supply chain domain" in order to appropriately leverage supply chain capability to improve PD and supply chain readiness (Van Hoek and Chapman, 2007). The supply chain operations reference model (SCOR 9.0) indicates that the fundamental expertise necessary to identify, prioritize and aggregate the requirements for the delivery system is rooted in the supply chain domain. In more specific terms, this relates to a good understanding of demand patterns, desired delivery times, legal and handling (e.g. safety, packaging) requirements. Moreover, the SCOR points out that the proficiencies necessary to identify, assess and aggregate the resources of the delivery system and balance them with the requirements is also anchored in the supply chain domain. In more concrete terms, this relates to a good understanding of production, warehousing and logistics capacity, as well as the effects on capital bound in inventory, cash-to-order cycles (SCOR 9.0).

As a consequence, we conclude that linkages between PD and the SC are necessary because the two domains are mutually dependent on their intellectual resources. Their mutual dependence is context-specific and expressed in DC objectives. The primary purpose of linkages is to enable the exchange and combination of intellectual resources across the two domains or, in other words, to facilitate the exchange and integration of context-specific knowledge and information.

> **Proposition #1**: *Effective linkages between Product Development and the Supply Chain are required to address critical interdependencies by exchanges and combination of intellectual resources.*

We next review the structure of linkages in the Development Chain performance and the parameters that impact on the propensity of linkages to support the accomplishment of DC objectives.

2.5. Dimensions of linkages in the Development Chain

A resource dependency theory lens indicated that interdependencies exist between PD and the SC that should be managed. In this section, we take a network perspective, which affords a more detailed description of the structure of the linkages between PD and SC and therefore helps to understand how they can be managed (Hatch, 2006, p. 333). We aim to show how specific DC networks can be designed for specific contexts and evaluated by managers, as well as examined by researchers. In accordance with Nahapiet and Goshal's (1998) discussion of social networks in an organizational context, we see the principal purpose of network linkages in the DC in the exchange and combination of intellectual resources between PD and the DC. We give specific attention to differences in the level of observation/analysis, (1) the sub-process level and (2) the level of groups and individuals. To our knowledge, prior scholarly work has not addressed this topic in depth in this context, and, hence, we see the following account as one of the major contributions of this chapter. Another contribution is that we present and discuss product and process complexity and the uncertainty that arises from them as important contextual factors in the Development Chain (see Section 2.4).

Whilst DC objectives can be organized by generic categories, they may be interpreted and implemented differently depending on the context. In other words, there is no set of DC objectives that is universal across industries, firms and development projects. As a result, the combination of intellectual resources (mostly procedural know-how, for example the skills and expertise necessary to manage the delivery system) required to accomplish DC objectives can vary significantly most noticeably at the project-level. Adaptation to specific DC objectives leads to variation in the necessary combination of intellectual resources between PD projects and therefore has implications for the nature of linkages between PD and the SC. A more detailed look is therefore required to show how specific intellectual resources can be exchanged and combined to contribute to specific DC objectives. For this purpose, we will next examine connections between the PD and the supply chain at a level where individuals or groups connect through specific sub-processes that have a unique content and thus afford the creation of combinations of distinct expertise and assets.

A view that connects PD and the SC at the sub-process level has been suggested by prior literature. For instance, Wheelwright and Clark, (1992) emphasize that a deep understanding of how and why the processes [that are part of developing a new product and satisfying customer needs by executing orders] are created, managed and driven the way they are is critical to PD success. Srivastava, Shervaney and Fahey (1999) also discuss the interdependencies of PD and SCM at the level of sub-processes. The authors suggest that connections between sub-processes are beneficial to better co-ordinating, streamlining and integrating the work in each sub-process. As a result, effective linkages may help to reduce unnecessary redundancies and error rates within and between sub-processes (Thaler, 2003). A perspective that places the primary linkages at the sub-process therefore has the advantage of putting focus on the exchange and combination of procedural knowledge or ‘know-how’. In addition, sub-process level connections imply coactivity and consequently are more conducive to the exchange and combination of valuable intellectual resources (Nahapiet and Goshal, 1998). Based on Srivastava et al’s (1999) work, Hult and Swan (2003) present a research agenda for the linkages between SC and PD that also places the connections between the two domains at the sub-processes level. Their research agenda identified 60 viable linkages at the sub-process level that should benefit PD performance. Undoubtedly, all 60 linkages are important, especially when a meta-level research agenda is proposed. In a similar approach, we propose a sub-process level view that examines the primary connections of the five PD sub-processes and the six SC sub-processes we introduced in Section 2.2 (see Figure 2.3).

We view this level of sub-process linkages as rich enough for meaningful analysis of the connections between PD and SC, yet simple enough to allow for both theoretical and empirical investigations of these connections. In this context, we view our contribution to be that we propose to study the connections between PD and the SC at a sub-process level that implies a workable number of linkages (as in Figure 2.3) hence allowing the exploration of empirical and managerial examinations that can illuminate important differences between DC networks. For example, our sub-process level view can allows us to examine the links among sub-processes during development with respect to their communication pattern and time, an important consideration as Wheelwright and Clark (1992) postulated.

More specifically, we next discuss how the proposed sub-process view allows us to measure, compare and contrast DC networks along four different dimensions: (1) network configuration, (2) intensity in terms of strength of linkages, (3) timing and (4) resource load associated with a node of the DC network.

2.5.1. Network configuration

As illustrated in Figure 2.3, a sub-process view breaks down PD and the SC based on content (e.g. product design content or order processing content). It is implied that the content is different for each sub-process and, therefore, the intellectual resources required to master different content vary as well. Thus, linking PD and the SC at the level of sub-processes makes it possible to create linkages that can enable specific combinations of intellectual resources. Among them, some combinations may be more valuable than others, within a PD project, as well as across PD projects, firms or industries. In fact, Zacharia and Mentzer (2007) suggested that the role and value of connections between logistics and PD may be different for each of the different sub-processes of PD. Vice versa, the role and value of PD may be different for each of the different sub-processes of the supply chain corresponding to the new product. For example, a linkage between *outbound logistics* and *product design* may focus on optimizing the product with respect to transportation requirements, whereas a linkage between *sourcing* and *procurement* may concentrate on component selection and cost of inputs. In sum, different PD projects with different contexts and different DC objectives may require different configurations in their DC networks.

It is important to emphasize that in a network configuration a linkage is present at any level of exchange between two sub-processes (i.e., regardless of the intensity with which knowledge and information is exchanged between the two sub-processes). Therefore, the difference in DC network configuration across different projects merely expresses the presence or absence of a linkage as a dichotomy. In other words, when supply chain [logistics] personnel attend PD meetings in principal constitutes a connection regardless of whether the logistics personnel offer any input during the meeting. However, Zacharia and Mentzer (2007) cautioned in this context that simply attending meetings together (without any meaningful exchanges of context-relevant process expertise) may not translate into any noticeable gains. Consequently, we consider strength, timing and resource load of a DC linkage as important dimensions which we discuss next.

2.5.2. Strength of the linkages

Prior empirical work that focused on the intersection of R&D with marketing reported an association between the intensity (strength) of linkages and performance (Kahn and Mentzer, 1998). Similarly, we expect that the strength of linkages is an important dimension of DC networks. Wheelwright and Clark (1992) suggest using communication parameters like frequency, direction and richness of media to capture the strength of linkages. Likewise, Kahn and Mentzer (1998) conceptualized a construct for the strength of linkages via the communication mode between them. Their work uses a spectrum between interaction and collaboration to measure the strength of linkages between R&D and Marketing. Because of the similarity in context, we envisage that the strength of linkages in the DC can also be conceptualized and measured via Kahn and Mentzer's (1998) constructs of communication modes.

As an illustration of the importance of the strength of linkages in DC networks, consider a product with a very simple distribution process, but a very complex production process. In this case, the linkages between PD sub-processes and production may require intensities that are significantly different from those between PD processes and outbound logistics. Therefore, linkages with different intensities may be required within the same PD project. Further, the strength of the same linkage may vary across different PD projects. As an example, think about the connection between product design and outbound logistics, which should be less critical for products that require optimization of transportation cubic space than for other products, where this is not the case. Another factor that determines the appropriateness of strength of a particular linkage could be the degree of readiness of the SC at the beginning of the PD project. In some cases the delivery system for a new product may already exist, in other cases it may have to be created in its entirety. It should be expected that in the latter case, stronger linkages are required to accomplish DC objectives.

2.5.3. Timing

The advantage of longer interactions between PD sub-processes has been noted Wheelwright and Clark (1992). They argued that when progress (with interdependent sub-processes) is made concurrently, a deeper mutual understanding is created and the effectiveness of the PD effort can be improved over a serial (one way or batch) connection. Likewise, we expect that the duration of interactions, which we refer to as timing of the linkages has performance implications for the Development Chain and therefore is an important dimension of DC networks. With respect to measurement of this dimension, we envisage an approach that is similar to Pisano's (1996) who applied a scalable method in a study of process development projects. His method determines the duration of interactions between PD sub-processes via the concept of temporal overlap, expressed as a percentage of PD project duration. In the same fashion, timing of DC networks can be measured via the PD sub-processes that afford the establishment of a timeline for each PD project. For example, the timing of a linkage between product design and procurement can be assessed and compared to other linkages using the temporal overlap of product design. At the aggregate level, the combination of connectivity between PD and the SC and the temporal overlap of PD sub-processes will reveal how the two domains were linked in time. As a consequence, timing can be used as a dimension to assess and compare DC networks across PD projects, firms and industries.

2.5.4. Resource load

It is important to note that tangible linkages in the DC – i.e., connections through which information, knowledge or assets are combined - unquestionably, can only exist between individuals, groups and the assets of the two domains. As Srivastava et al, (1999), p.170, suggest, "processes [in PD and SCM] are meaningless viewed in isolation of those people charged with implementing them". Therefore, designing and executing each sub-process in PD and the SC requires participation and interaction of people and assets. We define resource load in the context of the DC as the number of people and assets that are associated with the connections between sub-processes[2]. Depending on the nature of the PD project the number of people and assets as well as their level of involvement in sub-processes can vary significantly. For example, Ulrich and Eppinger (2011, p.5) compare five development projects and note that the peak size of the development team (internal and external participants) can range between 6 and 16,800 people. In this context, Sosa, Eppinger and Rowles (2004) examine how in complex development projects organizational complexity mirrors product complexity, in terms of size, structure and number of parts. Thus, depending on the nature of the PD project and the complexity of the new product, the resource load associated with a linkage between two sub-processes may vary significantly. Although conceptualizing the DC as a network may not allow us to capture all the intricacies of the connections between people and assets, it does allows us to capture in an aggregate sense the organizational efforts necessary to facilitate and maintain a specific sub-process link. In fact, we contest that a view that puts the primary connections between PD and the SC at the sub-process level is advantageous, because it reduces/collapses the resource load behind the nodes. As a consequence, the resource can be controlled for while the relative differences between the strength of linkages can be compared between PD projects with different resource loads.

2.6. Contextual factors in the Development Chain

2.6.1. The role of DC objectives as a contextual, moderating variable

In order to better illustrate and further support our argument that DC objectives constitute an important contextual factor that moderates the relationship between the DC network of linkages and DC performance, consider two different examples of new products, a mountain bike and an appliance, both with very different delivery systems. Appliances, say a refrigerator, typically exhibit a low clock-speed that corresponds to a slow rate of change in technology (Fine, 1998). Variety for refrigerators is typically low and their delivery systems are designed to be efficient (as with a Built-to-Stock supply chain). By contrast, producers of mountain bikes offer many more customization options to their end customers (as

---

[2] We should note that the strength of linkages is independent of the resource load; a PD project can have few people and assets who nevertheless communicate very intently, or a lot of people and assets who communicate infrequently.

with a Built-to-Order supply chain). Customers can choose exactly the gear and brake components, the saddle, and the suspension system that they want. These requirements for efficiency or flexibility create a specific context for the Development Chain that is different for the two products.

Figure 2.4 illustrates how the three generic categories of the DC objectives can be interpreted for the mountain bike example. The requirement for flexible configuration of the product creates the need to design and enable a responsive delivery system (DC objective 1). In addition, product design must be carefully matched with the assembly sequence (DC objective 2), and components from multiple origins need to be integrated successfully into the final product for prototyping and commercial supply (DC objective 3). To achieve these objectives, the procurement sub-process and the related processes of component suppliers should be linked to PD’s early processes, including product design, process design and development sourcing. Suppliers may ask their engineers and sales people to connect with the bike producer. And the procurement process within the bike producing firm connects to buyers and the product design and process design sub-processes, enabling engineers, scientists and CAD designers to communicate with buyers. In addition, in order to match the assembly sequence with variations in product configuration, a connection between production and product design, as well as process design, respectively will be required. The PD effort may further benefit from linking its assets, such as its drawing system with suppliers’ CAD systems during product design and process design. The resulting network of linkages is shown in Figure 2.4.

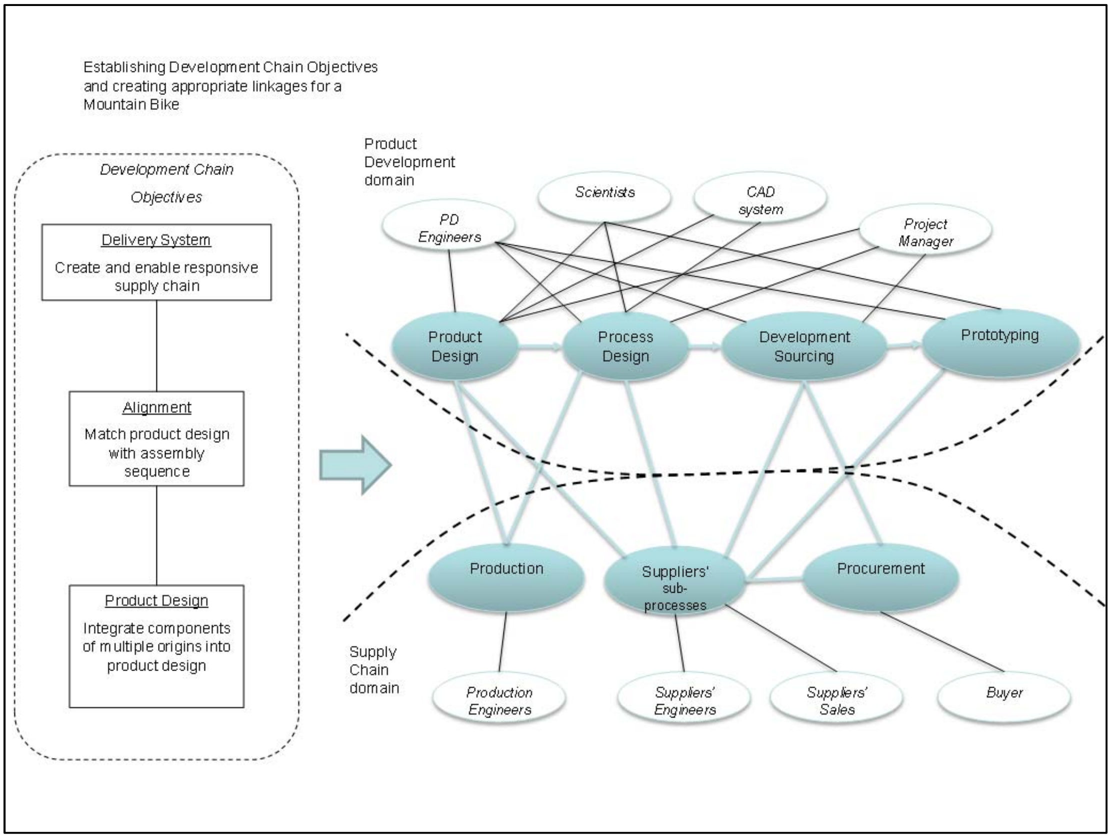


Figure 2.4 **Example of establishing DC objectives and creating appropriate linkages in the Development Chain for a Mountain Bike**

Conversely, for a refrigerator, designing and enabling an efficient delivery system would be a top priority (DC objective 1). The components and parts of the product should be standardized and stable to a large extent and be purchased in bulk to achieve economies of scale (DC objective 2). The key to an effective product design would be to allow for a streamlined in-flow of raw materials and assembly of the product (DC objective 3). To achieve these objectives, the primary connections should be between inbound logistics, production, and production planning in the SC domain and process design in the PD domain. In addition, development sourcing and prototyping may benefit from a linkage to suppliers' assets, like electronic catalogues of standard parts and components. The increase in visibility and accessibility will allow replacing or substituting them rapidly during prototyping. The resulting web of linkages is shown in Figure 2.5.

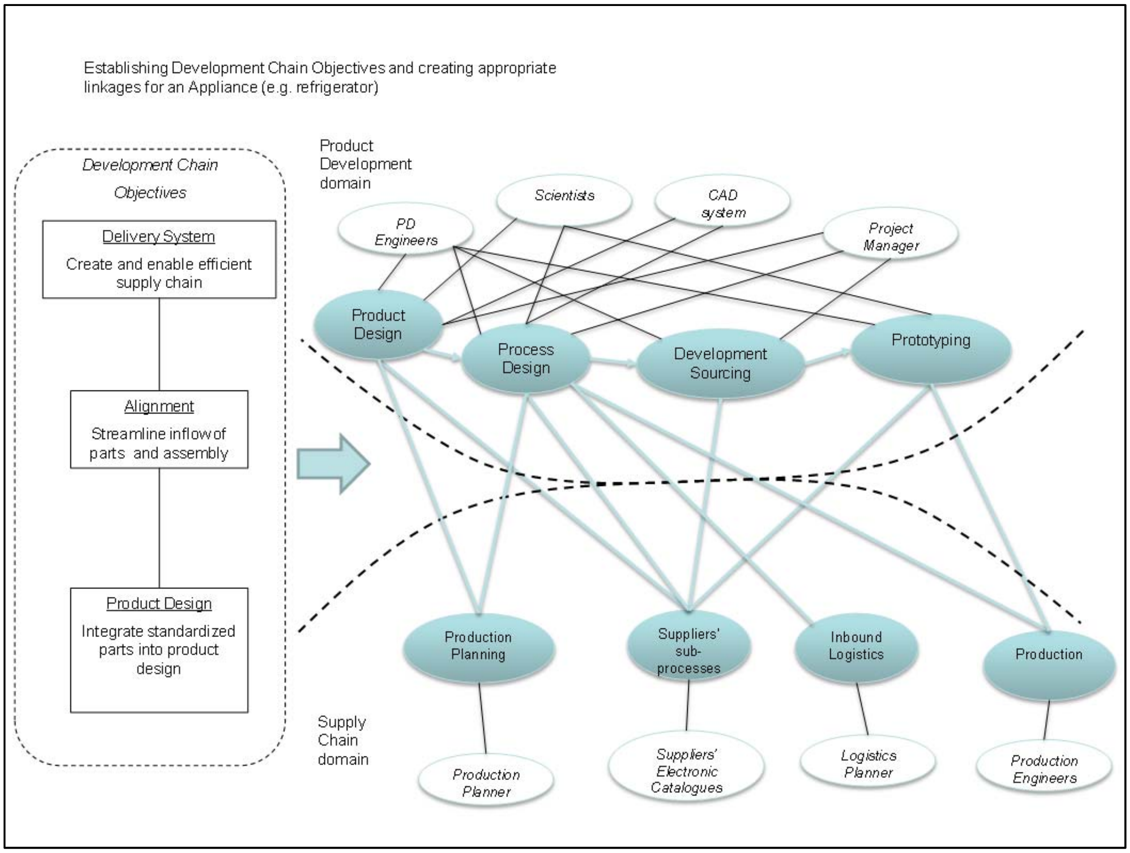


Figure 2.5 **Example of establishing DC objectives and creating appropriate linkages in the Development Chain for in the Development Chain for an Appliance**

Although the two examples are not all inclusive case analyses, they do serve to illustrate that in the case of the mountain bike less linkages (7) are present between sub-processes than for the appliance (9). At the same time, more resource load exists for the mountain bike (16 connections between sub-processes and resources) than for the appliance (15). Hence, the two contexts require different network configurations and resource load. In addition, it seems intuitive that the requirements on the linkages in terms of timing and strength differ as well. For example, the mountain bike seems to call for earlier and more intense linkages with component suppliers than it is the case for the appliance.

It should be noted that our account does not differentiate between effective linkages that are self-actuated, mandated by policy, created ad-hoc by managerial decision-making or through prior planning. However, we argue that DC networks that are tailored to match the context in terms of DC objectives will benefit DC performance.

Proposition #2: *Linkages between Product Development and the Delivery System will benefit DC performance, if their four dimensions (network configuration, strength, timing and resource load) are tailored to accomplish specific Development Chain Objectives.*

2.6.2. The moderating role of product and process complexity

Our examples and discussions above highlighted an important aspect of the Development Chain: not all products are alike. Consider, for instance, aligning the product architecture, delivery timing and assembly sequence for a small private airplane and compare it to an Airbus A380. They must be different, but why?

The first answer points to the difference in size and complexity of the two products. Sosa, Eppinger and Rowles (2004), for example, note that product complexity is an important factor in development, because of the large number of physical components and players involved in the process. At the same time, Novak and Eppinger (2005) find that product complexity is an important factor in the supply chain, specifically for procurement. As a consequence, we argue that product complexity is an important contextual factor in the Development Chain.

The most obvious way by which product complexity is elevated is when the number of parts/components of a product increase and when there are more complex interactions between them (Sosa, Eppinger and Rowles, 2004; Novak and Eppinger, 2005). However, complexity can be defined in a much broader way, as the degree of difficulty in understanding and predicting the properties of a particular system. Complexity is also known to be a key factor involved in creating complicated processes or situations. For instance, Novak and Eppinger (2005) include the degree of newness or innovativeness as a determinant of product complexity. Newness, of course, is a matter of perspective. Garcia and Calantone (2002) argue the degree of newness depends on the kind of discontinuities caused by a new product and who is affected by them. Accordingly, products can be new and create a discontinuity for (1) the scientific community in a technology space, (2) the product development team, (3) the processes to make and deliver the product and (4) the marketplace. The more areas are affected the more ambiguity and complexity is created.

Garcia and Calantone's (2002) work implies that the degree of newness impacts not only product complexity but also the processes necessary to develop, produce and deliver the product. Process complexity, therefore, is another important contextual factor in the Development Chain. Process complexity depends not only on the degree of newness but also on the strategic positioning of the new product and more generally on the uncertainty of the DC's decision-making processes. To understand how strategic intent may elevate process complexity, consider for example, the strategic positioning of a new product as a disruptive innovation (Christensen and Raynor, 2003) or as a product of attractive quality (Kano et al, 1984). Such positioning may bear its advantages and eventually lead to the creation of sustainable competitive advantage. On the other hand, the absence of applicable firm standards and industry benchmarks for such a product will introduce more uncertainty for the Development Chain and thus increase process complexity during development. Moreover, when there is a need to protect intellectual property or when it is in the best interest to have full control over performance of critical components or building blocks of the product, supplier interaction and sourcing decisions get more complex (Christensen and Raynor, 2003). In general, higher uncertainty in the activities and expected outcomes of DC decisions imply more complex problem solving processes and thus higher process complexity.

Taking all this into account, we expect that higher product and process complexity requires more intense linkages (expressed via stronger, earlier linkages, as well as higher resource load as discussed earlier) and managerial intervention in the Development Chain. Higher intensity is needed, because more components and interactions in the product need to be mirrored by the Development Chain structure (Sosa, Eppinger and Rowles, 2004). Moreover, a higher degree of newness and advanced strategic positioning of the product (Christensen and Raynor, 2003; Kano, 1986) will increase the degree of difficulty in understanding and predicting the product and the delivery system and thus higher intensity are required to better address difficulties and uncertainties.

Proposition #3: *The relationship between the accomplishment of Development Chain Objectives (DC performance) and effective linkages in the Development Chain is moderated by product and process complexity.*

We envisage proposition 3 as another key contribution of this chapter. Prior literature has, of course, presumed product complexity to be a key variable for the success of new products, but no work has presented it as a variable of the DC that can influence not only PD but also the linkages of PD with the SC.

2.7. DC performance indicated via financial success with new products

The purpose of this section is to show how Development Chain performance can be connected to financial success with a new product, the central performance indicator from the PD literature. It is possible to measure DC performance directly by quantifying how effectively and efficiently a supply chain operates, if a product design is optimized and how well the product and the supply chain are aligned. However, because DC objectives are so context specific – one PD project may place more emphasis on an efficient supply chain than on a flexible product design, whereas another may focus solely on a product design that protects the product in transit –it is hard to compare how effective the DC linkages are/were across different PD projects. Moreover, it may be difficult to quantify DC performance in a generalizable way, because the objectives may in practice often be expressed as qualitative goals. Consequently, we will argue that return-based measures are good indicators of DC performance. But first, we will define financial success in our context and show how it appropriately captures both product as well as supply chain effectiveness.

Prior work in the PD literature suggests that measuring the success with new products should be connected to "the ultimate dependent variable in management science", profitability or (economic) rent (Verona, 1999; Ernst, 2002). Accordingly, financial success with new products that is indicated via return-based measures like the *net present value* (NPV) or the *internal rate of return* (IRR) has been established as a common performance variable in PD research and practice (Brown and Eisenhardt, 1995;

Kerzner, 2001; Ulrich and Eppinger, 2011). Return-based measures are appropriate in a development context, because they capture the cash flows incurred before and generated after the launch of the new product as well as time-value of money. Previous concepts of financial success with new products present two main pre-cursors of financial performance that determine returns from a new product: *PD project performance* and *product effectiveness*, both of which are secondary constructs (Brown and Eisenhardt, 1995; Verona, 1999). The former, PD project performance, is assessed by how quickly a product idea gets converted into a launch-able product (*time-to-market*) and by how productive the development resources are (*productivity*). Thus, PD project performance accounts for the financial burden that is created before the launch and whether the new product was launched within its window of opportunity. Product effectiveness, put broadly, subsumes attributes that contribute to meeting and exceeding customer expectations (Verona, 1999). Among them are technical *performance*, *quality*, *style* and *cost* of the new product (Brown and Eisenhardt, 1995). Because product effectiveness includes cost and strongly affects how many customers will buy the new product and when, it is a major pre-cursor of the cash flows from a new product after launch.

In addition to product effectiveness, as described above, supply chain performance is a key component of a new product's success. Customer expectations increasingly include product attributes that depend on supply chain performance, like convenience (the ability to easily find, purchase and receive a product), product selection and product customization (Fixson, 2005; Simchi-Levi et al, 2008). In accordance with contemporary concepts of value creation the product and its supply chain can be differentiated as a bundle that is more attractive to customers than the physical differentiated product alone (Grant, 2010). Supply chain performance is also an important component of product cost. Therefore, in agreement with Lambert and Pohlen (2001), we take a broader perspective on product costs, as we view them as total expenses incurred to deliver the product. The cost to deliver an order for a new product includes the costs for parts and components, their fabrication and assembly, but also important transactional costs associated with acquiring inputs, co-ordination cost across the supply chain[3] and holding cost for inventory (Thaler, 2003; Simchi-Levi et al, 2008). In other words, supply chain performance is an important pre-cursor of the magnitude of cash flows from a new product after launch and can improve the timing of cash flows from a new product after launch, because cash flows depend on parameters like the order fill rate and the cash-to-order (or cash-to-cash) cycle time (Croxton, 2003; Simchi-Levi et al, 2008)[4].

Overall, so far we have argued that financial success with new products, as we present it (to include product performance as well as SC performance), appropriately captures performance of the new product and its supply chain as a bundle. Furthermore, financial success is neutral to interpretation with respect to performance, because it can be raised by raising the attractiveness of the product alone, of the bundle of product and the SC or by increasing the efficiency of supply chain operations to lower costs, or all three simultaneously. Lastly, financial success is neutral to industry, firm or project context (PDMA handbook). Therefore, we conclude that financial success with new products measured via return-based indicators represents a suitable ultimate performance indicator for the Development Chain.

We are now in a position to connect the accomplishment of each of the DC objective with our ultimate performance indicator for the DC. We begin with the first DC objective, the creation and enabling of the delivery system. The genesis of the delivery system for a new product includes the establishment of its structure (network) and the processes for its operation. For example, the channels for purchasing and distribution activities are typically created during development (Krishnan and Ulrich, 2001). Also included in the establishment of the delivery system is a decision about how each channel is monitored and controlled (Lambert and Cooper, 2000). A linkage between PD and the SC can play an important role in supporting the accomplishment of both tasks. For example, information and knowledge about the new product that will eventually be captured in drawings, bills of materials and component

---

[3] This includes costs for logistics, manufacturing and information systems; the difference between the best-in-class and the rest amounts to as much as 5% of the total product cost

[4] The difference in cash-to order cycle time between best in class (30 days) and median performers (100 days) can be 70 days; best in class order fill rate is approaching 100% (94%); the median ranges depending on industry 69-81%

specifications is critical to select suppliers and establish appropriate relationships. In addition, information and knowledge about the new product can be applied to generate preliminary forecasts, production plans, assembly sequences and the selection of optimum batch sizes (Thaler, 2003). In sum, we expect that the accomplishment of the first DC objective will be reflected in lower co-ordination costs, transactional costs, holding costs and higher order fill rates. Thus, we postulate:

> **Proposition #4**: *The creation and enablement of the delivery system by the Development Chain will improve financial success with new products.*

Financial success with new products can also be improved, if the new product design is optimized by the combined expertise from product development and supply chain (i.e. when the second DC objective is accomplished). Product design can benefit from supply chain expertise, specifically, when (1) shipping conditions affect the final product, (2) product launch is critical and there is a need to distribute product to a large number of buyers in a short time, (3) the physical configuration of the product may prevent efficient utilization of assets, (4) the cost of distributing the product and providing the inputs is a significant component of the cost of the product and, finally, (5) the existing method of distribution will be changed (Zacharia and Mentzer, 2007). Practitioner terms for an approach that optimizes product designs, specifically to support the operation of the delivery system, are *design for manufacturing* (DfM) or *design for logistics* (DfL).

Another area to advance product designs with the help of the supply chain is to leverage supplier expertise to elevate product performance or to better integrate their components in the product and its assembly process (Petersen, Ragatz and Handfield, 2005; Bengtsson, VonHaartman and Dabhilkar, 2009). Consequently, we expect that the accomplishment of the second DC objective will raise the attractiveness of the new product (product effectiveness) and improve the performance of its supply chain in terms of lower co-ordination costs, transactional costs, holding costs and higher order fill rates. Therefore, we conjecture:

Proposition #5: *The optimization of product design by the Development Chain will improve financial success with new products.*

Finally, DC performance can have a positive impact on financial success with new products, when the new product and its supply chain are appropriately aligned. Critical to alignment are, for instance, strategic decisions about sourcing of components and order fulfillment. Typically, both decisions need to be made during the development effort (Krishnan and Ulrich, 2001).

With respect to sourcing of components for a new product, the principal choice is to insource (make) or outsource (buy). Insourcing is typically chosen to retain full control over the overall design and functionality of the new product or to prevent loss of critical technological know-how and hold-up. Outsourcing can be chosen to lower cost, for instance, by leveraging competition among suppliers or by talking advantage of economies of scale on the supply side. However, outsourcing can also be chosen for innovation, by leveraging supplier expertise (Clark and Fujimoto, 1991; Bengtsson et al, 2009). Accordingly, the appropriateness of the choice of sourcing, depends on whether the new product will benefit more from innovation or from lowering its cost.

With respect to the decoupling point, the principal choice is to deliver new products with a built-to-stock (BTS) or a built-to-order (BTO) supply chain (Olhager, 2003; Gunasekaran and Ngai, 2005; see Chapter 4). BTS supply chains are appropriate for products that customers demand at low cost and off-the-shelf availability. BTO supply chains have become more popular in recent years because customer preferences are not limited to performance, style or price tag of the product any longer. Customers increasingly expect choice between multiple versions of a new product (some relate to style, like the color of a vehicle, others to performance, such as the size of a hard-drive in a computer) (Fixson, 2005).When the choice of decoupling point aligns with a new product's demand characteristics, the new product and its delivery create customer satisfaction as a system, rather than just via the product itself. In sum, we expect that the alignment will raise the attractiveness of the bundle of the new product and its supply chain, as well as supply chain performance, in terms of transactional cost.

Proposition #6: *The alignment between the new product and its delivery system by the Development Chain will improve financial success with new products.*

2.8. Conclusion, Managerial Implications and Future Research

This chapter has continued a line of inquiry into the intersections of product development and the supply chain, which prior research has described as the Development Chain (Simchi-Levy et al, 2008). Precisely, it has examined how effective linkages between product development and the supply chain for a single product can benefit the accomplishment of specified objectives that require a union of selected contributions from each domain.

We have argued that the viable and appropriate choices on how to establish and maintain effective linkages depend on the formulation of Development Chain objectives according to context as well as on product and process complexity. Specifically, our conceptual model views product and process complexity as well as the formulation of DC objectives as important contextual factors, which both moderate the relationship between DC linkages and DC performance. We have aimed to add more precision and texture to prior conceptualizations of the Development Chain by defining it as the area where Development Chain objectives are formulated, product and process complexity is analyzed and effective linkages between PD and the SC are formed. By clearly representing the DC as the union of processes and structures in PD and the SC we were able to demonstrate how effective linkages depend on the DC objectives. We did so by conceptualizing linkages of the DC as a network that connects individuals and groups through the sub-processes and their content. This conceptualization allowed us to clearly demonstrate how different connections among DC sub-processes can impact the accomplishment of DC objectives.

With respect to DC performance, we have established financial success with new products, measured via return-based indicators, like NPV, as a suitable ultimate performance indicator for the DC that adequately captures the performance of the product and its supply chain and that is neutral to context.

Furthermore, we have tied the accomplishment of three categories of DC objectives to financial success with new products.

We see the managerial implications of this study as follows: The core managerial task in the Development Chain is to appreciate that the viability and potential of choices about inter-domain linkages are determined by product/process complexity and the DC objectives that were set in the first place. Therefore, it is imperative to fully understand the new product and its complexity in terms of the dimensions we have discussed and to establish the right Development Chain objectives. Our conceptualization of DC linkages is based on a network that connects content-based sub-processes and functional representatives across the two domains. This particular perspective and the four dimensions (of network configuration, strength of linkages, timing and resource load) along which DC networks differ will help managers to establish or foster the appropriate linkages in order to mine and combine the required expertise. Once linkages are established, visibility is created and exchanges are enabled, the importance of the accomplishment of Development Chain objectives can be better communicated and incentivized. Because of the expected impact on return-based indicators, Development Chain success can be rewarded across both domains based on gains in financial success with new products.

We trust that because the interdisciplinary area of the nexus of product development and supply chains is still an under-researched territory, this study and our conceptual model will aid to advance the research agenda in this area. To that end, our conceptual model opens up a number of avenues for future empirical interdisciplinary research.

The first and obvious opportunity is to study the array of interdisciplinary objectives that require contributions of PD and SC during development across firms, possibly industries, and confirm or refute that they converge on and fit into the three categories we have described in this chapter. Another opportunity is to contrast successful and non-successful development projects based on differences in their network configuration and the intensity of exchanges between PD and the SC. A third possibility is to test how much of the success with new products can be explained by an alignment between the product and its delivery system. For example, empirical studies could determine the effect of (mis)alignment between product interface characteristics and upstream (sourcing/procurement) supply chain strategies on financial success with new products. Such investigations could include an assessment of the effects of (mis)alignment between product architecture characteristics and downstream (delivery/order penetration point) supply chain strategies. A conceptual discussion of these topics is included in Ulrich's (1995) and in Fixson's (2005) articles.

The latter two opportunities lead to an important question: How can one contrast the impact of Development Chain success against other factors that have an influence on and account for differences in product success? Brown and Eisenhardt's model (1995), for example, propose that the majority of success factors exert themselves on PD project performance. In other words, their impact is captured in the cash-flows from before the new product is launched. Other factors, like customers, executive management and project leadership impact on product effectiveness, and by extension on the cash flows derived after launch. However, by contrast to DC performance, the impact of these factors will be known very shortly after the product is launched. Therefore, perhaps the best way to gauge gains in product success from Development Chain performance may be to concentrate on long-term post-launch performance. In other words, to compare the expected returns at time of launch with the actual returns at a post launch review, several months or years after the new product has been launched. To summarize, empirically testing and comparing the impact of Development Chain performance with traditional PD success factors presents a potent research opportunity.

The last potential research opportunity also stresses the limitations of this early exploratory work. Although, we have added sufficient rigor and strengthened our account with findings from prior conceptual and empirical work, more qualitative work would benefit this important area. For example, much of our initial insights (including the examples) and part of what has led to the core ideas for this chapter have been derived inductively through a thorough review and understanding of prior literature, personal work experience and unstructured exchanges with researchers and practitioners in supply chain management and product development. Therefore, more in-depth, structured and rigorous case studies could test our model.

References

Bengtsson, L., Von Haartman, R., Dabhilkar, M.. 2009. Low-cost versus innovation: Contrasting outsourcing and integration strategies in manufacturing. ***Creativity and Innovation Management***. Volume 18, Number 1

Brown, S.L.; Eisenhardt, K.M. 1995. Product development: past research, present findings, and future directions. ***Academy of Management Review*** 1995, Vol. 20, No. 2, 343-378.

Carlile, P. R. 2002. A pragmatic view of knowledge and boundaries: Boundary objects in new product development. ***Organization Science***. 13(4) 442–455.

Christensen, C.M. and Raynor, M.E. 2003. ***The innovator's solution: Creating and sustaining successful growth.*** Harvard Business School Press: Boston, MA

Christensen, C.M.; Kaufman, S.P.; Shih, W.C. 2008. Innovation killers: How financial tools destroy your capacity to do new things. ***Harvard Business Review***. Reprint R0801F

Cohen, W.M., Levinthal, D.A. 1990. Absorptive capacity: A new perspective on learning and innovation. ***Administrative Science Quarterly***, Volume 35 number 1.

Crawford, M.; Di Benedetto, A. 2008. ***New products management***. Mc Graw-Hill, New York, NY.

Croom, S.; Romano, P.; Giannakis, M. 2000. Supply chain management: An analytical framework for critical literature review. ***European Journal of Purchasing & Supply Management*** 6 (2000) 67}83

Croxton, K.L., Garcia, S.J., Lambert, D.M., Rogers, D.S. 2001. The supply chain management process. ***International Journal of Logistics Management*** 2001 Vol.12, No.2

Croxton, K.L. 2003. The order fulfillment process. ***The International Journal of Logistics Management***. Volume 14, Number 1. 2003

Deeds, D.L., Decarolis, D., Coombs, J. 2000. Dynamic capabilities and new product development in high technology ventures: An empirical analysis of new biotechnology firms. ***Journal of Business Venturing*** Volume 15, Issue 3, May 2000, Pages 211–229

Dougherty, D. 1992. Interpretive barriers to successful product innovation in large firms. ***Organization Science***, 3: 179-202.

Dougherty, D. and Dunne, D.D. 2011.Organizing ecologies of complex innovation. ***Organization Science***, Articles in Advance, pp. 1–10

Ernst, H. 2002. Success factors of new product development: A review of the empirical literature. ***International Journal of Management Reviews***, Volume 4 Issue 1 pp. 1–40

Fixson, S. 2005. Product architecture assessment: A tool to link product, process and supply chain decisions. ***Journal of Operations Management***, 2005 Vol.23

Forza, C., Salvador, F., Rungtusanatham, M. 2005. Coordinating product design, process design, and supply chain design decisions. Part B. Coordinating approaches, trade-offs, and future research directions. ***Journal of Operations Management***, 23.

Garcia, R.; Calantone, R. 2002. A critical look at technological innovation typology and innovativeness terminology: A literature review. ***The Journal of Product Innovation Management***, 19 (2002) 110—132

Hatch, M. J. 2006. ***Organization Theory***. 2nd edition. Oxford University Press: Oxford

Hauser, J.; Tellis, G.J.; Griffin, A. 2006. Research on innovation: A review and agenda for marketing science. ***Marketing Science***,Vol. 25, No. 6, November–December 2006, pp. 687–717

Hippel, E. v. 1986. Lead users: source of novel product concepts. ***Management Science***, 32, 791–805.

Hult, G.T.M.; Swan, K.S. 2003. A research agenda for the nexus of product development and supply chain management processes. ***Journal of Product Innovation Management***, Vol. 20, Issue 5: 333–336

Kahn, B. 2005.***The PDMA Handbook of New Product Development***. 2nd edition. John Wiley & Sons, Hoboken, NJ.

Kano, N., Seraku, N.; Takahashi, F.; Tsuji, S. 1984. Attractive quality and must-be quality, Hinshitsu. ***The Journal of the Japanese Society for Quality Control***, (April 1984), pp. 39 -48.

Kerzner, H. 2001. ***Project management: A systems approach to planning, scheduling, and controlling***. John Wiley & Sons, Hoboken, NJ.

Krishnan, V. and Ulrich, K.T. 2001. Product development decisions: A review of the literature. ***Management Science*** Vol. 47, No. 1, January 2001 pp. 1–21

Kusunoki, K.Nonaka, I. and Nagata, A. 1998. Organizational capabilities in product development of Japanese firms: A conceptual framework and empirical findings. ***Organization Science*** , Volume 9, Number 6.

Lambert, D.M. and Cooper, M.C. 2000. Issues in supply chain management. ***Industrial Marketing Management***. 29

Lambert, D.M.; Pohlen, T.L. 2001. Supply chain metrics. ***The International Journal of Logistics Management***,Volume 12, Number 1

Lambert, D.M.,Croxton, K.L., Garcia, S.J. 2005. An evaluation of process-oriented supply chain management frameworks. ***Journal of Business Logistics Management*** 2005

Leonard-Barton, D. 1992. Core capabilities and core rigidities A paradox in managing new product development. ***Strategic Management Journal,*** 13, 5: Special Summer Issue, 111-125

McKone-Sweet, K., Lee, Y.-T. 2009. Development and analysis of a supply chain strategy taxonomy. ***Journal of Supply Chain Management***. Volume 45, Number 3.

Nahapiet, J., Ghoshal, S. 1998. Social capital, intellectual capital and the organizational advantage. ***The Academy of Management Review***, 23 (2)

Novak, S. and Eppinger, S.D. 2001. Sourcing by design: Product complexity and the supply chain. ***Management Science***, 2001 Vol.47, No.1

Olhager, J. 2003. Strategic positioning of the order penetration point. ***International Journal of Production Economics*** Volume 85, Issue 3, 11 September 2003, Pages 319-329 Structuring and Planning Operations

Pauwels, K.; Silva-Risso, J.; Srinivasan, S.; Hanssens, D.M. 2004. New products, sales promotions, and firm value: The case of the automobile industry. ***Journal of Marketing***, Vol. 68 (October 2004), 142–156

Petersen, K.J., Handfield, R.B., Ragatz, G.L. 2005. Supplier integration into new product development: Coordinating product, process and supply chain design. ***Journal of Operations Management,*** 23.

Pfeffer, J. Salancik, G.R. 1978. ***The external control of organizations: A resource dependence perspective***. Harper and Row: NY

Pisano, G. 1996. ***The development factory.*** Harvard Business School Press. Boston, MA

Rungtusanatham, M., Salvador, F., Forza, C., Choi, T.Y. 2003. Supply-chain linkages and operational performance: A resource-based-view perspective. ***International Journal of Operations and Production Management***, 23 (9)

Searcy, T. 2008. Companies don't compete, supply chains compete. ***http://answernet.wordpress.com/2008/11/24/companies-dont-compete-supply-chains-compete***

Simchi Levi, D.; Simchi-Levi, E.; Kaminski, P. 2008. ***Designing and managing the supply chain***. McGraw-Hill, NY

Sosa, M.E., Eppinger, S.D., Rowles, C.M. 2004. The misalignment product architecture and organizational structure complex product development. ***Management Science***, Volume 50 Number 12

Srivastava, R.K., Shervani, T.A. & Fahey, L. 1999. Marketing, business processes, and shareholder value: An organizationally embedded view of marketing activities and the discipline of marketing. ***Journal of Marketing,*** Vol. 63 (Special Issue 1999), 168-179

Srinivasan, S.; Pauwels, K.; Silva-Risso, J.; Hanssens, D.M. 2009. Product innovations, advertising and stock returns. ***Journal of Marketing*** Vol. 73.

Supply Chain Council. 2008. ***Supply chain operations reference model, SCOR 9.0*** www.supply-chain.org

Tatikonda, M.V., Stock, G.N. 2003. Product technology transfer in the upstream supply chain. ***Journal of product innovation management***, 20

Thaler, K. 2003. ***Supply chain management: Prozessoptimierungen in der logistischen kette***. Fortis im Bildungsverlag EINS, Troisdorf.

Thomke, S.; Von Hippel, E. 2002. Customers as innovators. ***Harvard Business Review*** 2002

Ulrich, K. 1995. The role of product architecture in the manufacturing firm. ***Research Policy*** 1995 Vol.24

Ulrich, K.; Eppinger, S.D. 2011. ***Product design and development***. McGraw-Hill

Van Hoek, R. Chapman, P. 2007. How to move supply chain beyond cleaning up after product development. ***Supply Chain management: An International Journal***, Vol. 12, No. 4, pp.239-244

Verona, G. 1999. A resource-based view of product development. ***Academy of Management Review***, Vol. 24, No. 1 (Jan., 1999), pp. 132-142

Wheelwright, S.C. and Clark, K.B. 1992. ***Revolutionizing product development.*** The free press. New York, NY.

Zacharia, Z.G., Mentzer, J.T. 2007. The role of logistics and you product development. ***Journal of Business Logistics***. Volume 28 Number 1

Chapter 3 Linking problem-solving sites between Product Development and the Supply Chain

3.1. Introduction

The idea that Product Development (PD) and Supply Chain Management (SCM) are core business processes that are both critically important to the firm is not new (Srivastava, Shervaney and Fahey, 1999). Lambert and Cooper (2000), for example, note that “new products are the lifeblood of a corporation” and “product development is the lifeblood of a new company’s products”. In addition, scholars like Croom, Romano and Giannakis (2000) noted that at least “in some parts of the literature” the supply chain is recognized as the central unit of competition. More recently, in 2008, the CIO of Norton, an influential practitioner, stated that “firms don’t compete, supply chains compete”.

Preceding research has also recognized the importance of the nexus between New Product Development (NPD) and Supply Chain Management (SCM) (Srivastava, Shervany and Fahey, 1999; Krishnan and Ulrich, 2001; Hult and Swan, 2003, Forza, Salvador and Rungtusanatham, 2005; Simchi-Levi, Simchi-Levi, Kaminski, 2008). Srivastava, Shervany and Fahey (1999), for example, note that “exploiting their interdependencies is more likely to lead to market success than focus on just one.” Interestingly, while product development and supply chain management have been established as important concerns in management (research and practice), there is still a considerable research deficit at their intersections and ample opportunity for scholarly work in this area (Hult and Swan, 2003; Lau, Yam, Tang, 2007). Prior scholarly work exists that focuses on isolated linkages between product development and particular areas of the supply chain (SC), such as logistics, suppliers, customers and manufacturing (Sethi, Smith and Whan Park, 2001; Thomke and Von Hippel, 2002; Tatikonda and Stock, 2003; Petersen, Handfield and Ragatz, 2005; Zacharia and Mentzer, 2007). However, studies that examine the intersection between PD and the supply chain comprehensively across multiple linkages (e.g. linkages across customers, suppliers and different sub-processes) and tie them to a common performance indicator, to our knowledge, do not exist. This state of affairs is constricting for managerial practice and research, especially because typically during development efforts the multiple interdependencies with the supply chain domain need to be addressed simultaneously. Accordingly, and put broadly, this chapter aims to contribute to a more comprehensive understanding of how multiple linkages between PD and the SC affect a common performance indicator that is success with new products. In accordance with prior literature, we define success with new products via the accomplishment of financial goals and we base our investigation on contrasting successful with unsuccessful PD projects (Cooper, 2005).

Our unit of observation is a PD project and our level of analysis is at the network of linkages between nodes that represent sub-processes in the PD and the SC domain as described in Chapter 2. The scope of our network includes linkages between internal sub-processes, as discussed by Srivastava et al (1999) or Hult and Swan (2003), but also incorporates external linkages to customer and supplier processes, as suggested by Rungtusanatham, Salvador, Forza and Choi (2003) and Thaler (2003). A network perspective is advantageous in our context, because it allows us to examine and compare systems of connections of sub-processes across PD projects, firms and industries. In addition, the structure of networks allows us to examine linkages between the two domains at different levels within a single research setting: the aggregate-level, the level of individual, dyadic ties or the level of groups, bundles of co-dependent linkages.

We build our investigation on a specific but common perspective that views PD as an act of distributed and collaborative problem-solving (Clark and Fujimoto, 1991; Iansiti and Clark, 1994; Braha and Bar Yam, 2004). With this specific focus, problem-solving performance during PD is a major pre-cursor of success with new products. Successful problem-solving, in turn, depends on access to information, knowledge and ideas. In previous studies with a focus on problem-solving during PD, access to more diverse intellectual resources has been shown to be beneficial (Sethi, Smith and Whan Park, 2001; Atuahene-Gima, 2003). Consequently, and in accordance with prior research (see for example Nahapiet and Goshal, 1998) we view the network between sub-processes as a critical problem-solving enabler, because its linkages facilitiate the exchange and combination of problem-solving inputs (information, ideas and knowledge). We contribute in this area by using the concepts of *practice* and *sites* (see Nicolini, 2010) as an appropriate theoretical and empirical lens that explains how sharing and applying information, knowledge and ideas among sub-processes in the network helps problem solving during PD. Further, in order to confirm the suggested relationship between network structure and problem-solving performance, we develop an *aggregate-level involvement* construct (Section 3.5) that captures the total number and intensity of exchanges along PD and SC linkages and investigate the following question:

> *Research Question #1: What is the effect of aggregate-level involvement between product development (PD) and the supply chain (SC) on the ability to support complex problem-solving activities?*

We address this question based on a review of prior literature and empirically. Whilst we expect that a higher level of aggregate-level involvement between PD and the SC may be beneficial to problem-solving when the problem is complex, its effect on overall success with new products may not be as clear. First of all, not every PD problem is complex such that it involves multiple interdependencies. In addition, excessive connections between PD and the SC may create a disproportionate demand for resources. It is well understood that in the execution of each project there is a trade-off between cost, time and performance in terms of quality of output (Kerzner, 2001). For instance, empirical PD research has confirmed that successful new product development efforts need to appropriately conserve resources to minimize the burden for break-even and meet the window of opportunity for market entry with the new product (Ernst, 2002). For that reason, PD leaders may want to be selective and restrictive about which linkages between PD and SC are activated and to what degree. For example, it may be sensible to begin with specific combinations of linkages that are universally critical to problem-solving. We contribute in this area by identifying empirically linkages and groups of linkages that are critical to product success in a general context, regardless of project and industry context. Based on a synthesis of prior research, we will reason that the critical linkages can be identified by examination of the participative (exchange) intensity in the network of PD and SC sub-processes, because their intensity indicates to what extent vital problem-solving inputs are shared and applied. We will thus address the following research question:

Research Question #2: What are the critical problem-solving linkages in the network of sub-processes between PD and the SC?

Finally, because many development problems involve interdependencies across multiple sub-processes, we expect that to be effective, even critical linkages between PD and the SC cannot function in isolation. In other words, we conjecture some of them need to operate *in concerto* to have an impact on success with new products. Therefore, the final goal of this study is to identify groups of critical linkages between PD and the SC and to assess their impact on the success with new products.

Research Question #3: What is the impact of groups of critical problem-solving linkages in the network of sub-processes between PD and the SC on success with new products?

The chapter is structured as follows. First, we introduce and provide an overview of the perspective of product development as an act of problem solving. Next, we review literature that presents the supply chain as a problem-solving enabler during product development. We proceed with a detailed description of our empirical lens for effective problem-solving linkages between PD and the SC. We then develop and present five testable hypotheses, which is connected to and followed by a description of our methodology. Finally, we present and discuss our results, limitations of our study, as well as its implications for research and managerial practice.

3.2. Product development as an act of problem-solving and PD performance

Viewing product development as an act of distributed, collaborative problem-solving has a considerable history in the innovation literature (Pisano, 1996). The inherent element of "unknowability" in the development of many new products (Dougherty, 2007) often makes it close to impossible to "dream up" and plan for all the problems that may be encountered during a PD project. Therefore, the ability to detect problems and solve them as they materialize is a key success factor for PD. More specifically, what makes problem-solving performance critical for product development performance is its direct impact on timing, productivity and effectiveness of the PD project. Speed to market, productivity of the PD project, as well as the effectiveness of product and process designs created during the PD effort are the main pre-cursors of the ultimate performance indicator for product development, financial success with new products. Financial success with new products is determined by revenue, growth rate, profits and the overall returns achieved through the PD effort (Brown and Eisenhardt, 1995; Verona, 1999; Ulrich and Eppinger, 2011).

Another aspect that makes success with new products difficult is that a product development effort typically raises numerous interdependent problems that necessitate iterative loops between the problems and, for complex products, involves hundreds of individual contributions (Braha and Bar-Yam, 2004). When problems are resolved inefficiently during PD, excessive iteration can occur, which will inherently delay the PD project and hamper its productivity. Furthermore, when final solutions to PD problems are ineffective, there will most likely be downstream consequences for the new product (in terms of style, cost and product performance) and its processes (in terms of cost and process performance).

Central to each problem-solving process, or better, episode is a sequence of four principal steps: Simon et al (1987) noted that problem-solving requires (1) choosing issues that deserve attention, (2) setting goals, (3) finding or designing alternative courses of action and (4) choosing among alternative courses of action. The vital inputs for problem-solving are information, knowledge and ideas. What is implied by the four-step process is that problem-solving can either fail because problems remain unsolved or at an earlier point, because they remain undetected. Therefore, the inputs for problem-solving have a dual role as they support the detection as well as the resolution of problems. In the next section, we discuss more specifically how the supply chain domain can benefit problem-solving during product development, because it can provide ideas, information and knowledge that support the detection of important interdependencies between PD and the SC, as well as the generation of solutions to development problems.

3.3. The Supply Chain as a problem-solving enabler during Product Development

Prior research discusses how the supply chain can support and improve problem-solving during development in a number of ways: For example, linkages into the supply chain domain increase reach for information, ideas and knowledge – the vital inputs for problem-solving. Atuahene-Gima (2003) studies problem-solving in a PD context and presents reach as "the distance traversed to search for ideas and information". Reach can refer to, for instance, access to customers' inputs for problem-solving. The study concludes that an increase in reach can "increase the quantity and quality of ideas, information and knowledge that a PD team can access". Similarly, other research has examined the positive effect of linkages with the ecosystem of suppliers and customers that is the supply network on PD performance. For example, Thomke and von Hippel (2002) examine connections with "customers as innovators". Their work cautions that customer integration can be advantageous when "they can design and develop the application-specific part of the product". The work by Tatikonda and Stock (2003) and Petersen, Handfield and Ragatz (2005) focuses on connections to suppliers. Petersen et al (2005) find that supplier integration into new product development can benefit the design performance of a new product such that it results in a better design of the purchased component, a better design of the final product, as well as easier and less costly execution processes for the delivery of the component. In the same context, Tatikonda and Stock (2003) make an important distinction between suppliers that provide a new technology (technology supply chain) and other more established sources of high volumes of routine parts and components (component supply chain). They note that the technology supply chain typically begins to interact with the early product design phase whereas the component supply chain typically becomes a concern during the ramp-up phase of PD. Suppliers that are able to provide a new technology are critical, because in many cases their technology can help to better differentiate the new product.

Other scholarly work notes how problem-solving during PD may improve through connections with intra-firm sub-processes of the supply chain that facilitate the exchange and transformation of materials, assets and information required to create and deliver the final product to end customers. Most of this literature concentrates on marketing’s and manufacturing’s role in development (Olsen, Walker, Ruekert and Bonner, 2001; Sethi et al, 2001; Crawford and Di Benedetto, 2008). However, linkages between PD sub-processes and other supply chain sub-processes have garnered some recent attention, because of their propensity to benefit success with new products. Zara, the Inditex brand known for its “fast fashion” business model is a pertinent example of the benefits of linking customers, order processing and production planning with their product development processes. Their quick conversion of information about changes in customer preferences allows Inditex and its brand Zara to generate a significantly higher and effective new product introduction frequency than their competitors (Simchi-Levi et al, 2008, p.272; Rothaermel, 2013, p.211; “Global stretch – when will Zara hit its limits?”, The Economist, March 10th, 2011). More recently, Zacharia and Mentzer (2007) were able to confirm that logistics’ involvement is beneficial to product development. Specifically, product design can benefit from logistics expertise, when (1) shipping conditions affect the final product, (2) product launch is critical and there is a need to distribute product to a large number of buyers in a short time, (3) the physical configuration of the product may prevent efficient utilization of cubic space, (4) the cost of distributing the product and providing the inputs is a significant component of the cost of the product and, finally, (5) the existing method of distribution will be changed.

Additionally, linkages between PD and the SC can also enable better detection of interdependencies between the two and formulation of solutions to address them. Srivastava et al (1999) noted that PD and SCM are not independent and their interdependencies need to be addressed to be successful in the marketplace. For instance, it is clear that effective design for ‘X’ [5] requires a thorough understanding of the product design process, as well as the logistics or manufacturing processes (Wheelwright and Clark, 1992). Furthermore, the interdependence between PD and the SC is emphasized as several important decisions about the supply chain for a new product are made during development (Krishnan and Ulrich, 2001). Petersen et al (2005), for instance, note that supply chain design is

---

[5] DfX can represent, for example, *design for manufacturing* (DfM) or *design for logistics* (DfL)

effectively determined during PD, when processes and information systems are specified, and the relationships with customers and suppliers are established. As a result, disconnects between PD and the SC or not paying attention to their interdependencies can have negative downstream consequences, such as when the product and the processes do not perform as intended (Simchi-Levi et al, 2008). Among the reasons that lead to product failure because of poor supply chain process performance are delivery of defective product, out-of-stock situations, or the opposite case, where inventory levels are significantly too high right after the product has been launched (Calantone, Di Bennedetto and Stank, 2005). Defective product and not filling orders are detrimental because they lead to unsatisfied customers, whereas high inventory levels raises supply chain cost in form of bound capital. One prominent example where substantial levels of unfilled orders and defective product occurred was the recent launch of the Airbus A380 (Petersen, 2009). Perhaps for those reasons, around one half (50%) of new products that have been approved to enter the development stage and launched are later classified as failures (Cooper, 2005; Barczak, Griffin and Kahn, 2009).

We conclude that recognizing and addressing the interdependencies between PD and the SC is an important part of the problem-solving effort during PD. Reach into the supply chain domain increases the quantity and quality of information, ideas and knowledge which are critical to problem-solving during development. Moreover, problem-solving between PD and the SC can benefit from multiple connections simultaneously. This is an important concern for the empirical part of our study as we identify multiple nodes where PD and the SC sub-processes should connect. In addition, we express connections among sub-processes in a way that allows the strength of their linkages to be compared and aggregated. In order to tie our empirical measure for the strength of linkages to the impact on problem-solving, we need to adequately theorize about the nature of effective problem-solving linkages between PD and the SC. For that reason, we dedicate the next two sections to identify, what constitutes a linkage between PD and the SC that can act as an effective problem-solving enabler.

3.4. Empirical lens: Linkages between PD and the SC that act as effective problem-solving enablers

3.4.1. A network of problem-solving linkages between sub-processes in PD and the SC

Because product development and the management of supply chains are vast areas of research and practice, a careful definition of scope is required for the empirical part of our study. As we choose our scope, we find support from prior work, for example, by Srivastava et al (1999) and Hult and Swan (2003), who note that we can expect to find and better understand the interdependencies between the two macro-constructs, PD and the SC, at a micro-level, between-their sub-processes. To that end, Chapter 2 presents a specific set of PD and SC sub-processes which connect, end-to-end, to customers and suppliers, as shown in Figure 3.1. The sub-processes are tied to and embedded in the supply network of the focal company.

They break down into five PD sub-processes (product design, process design, sourcing, protoyping and testing, launch and ramp-up) that facilitate the execution of product development and six SC sub-processes (order processing, production planning, procurement, inbound logistics, production, outbound logistics) that facilitate the execution of orders for the new product with the supply network. Splitting the macro business areas of PD and the SC into sub-processes allows the creation of combinations of specific content (e.g. product design content or order fulfillment content) that helps to address specific interdependencies. When we present processes as our nodes in a network of PD and SC linkages, we acknowledge that "processes are meaningless when viewed in isolation of those people charged with implementing them" (Srivastava et al, 1999, p.170). Thus, we fully consent to people being a fundamental part of each sub-process. In this context, we also view customers and suppliers as represented primarily by their processes. To that end, the next section will provide an illustration of how PD *processes* in general, as well as supplier and customer *processes* support PD problem-solving. We collapse the potentially many supplier and customer nodes in the supply network into four groups. In accordance with Tatikonda and Stock (2003), we categorize suppliers as tier 1 suppliers (for critical inputs, providers of technology) or tier 2 suppliers (for non-critical inputs; sources of routine parts and components). Customers are grouped into lead users, who represent the population that provides insight on how the product will be used, as discussed by von Hippel (1986) or Thomke and von Hippel (2002) and into demanders, who will provide insight into how a new product is purchased, in terms of quantities, timing and location (Croxton, 2003). The resulting image of viable linkages between PD and the SC in the context of our study is therefore that of a network of 11 internal and 4 external nodes. Five nodes represent sub-processes in the PD domain and ten (6+4) nodes represent sub-processes in the SC domain, for a total of 50 potential connections, as shown in Figure 3.1.

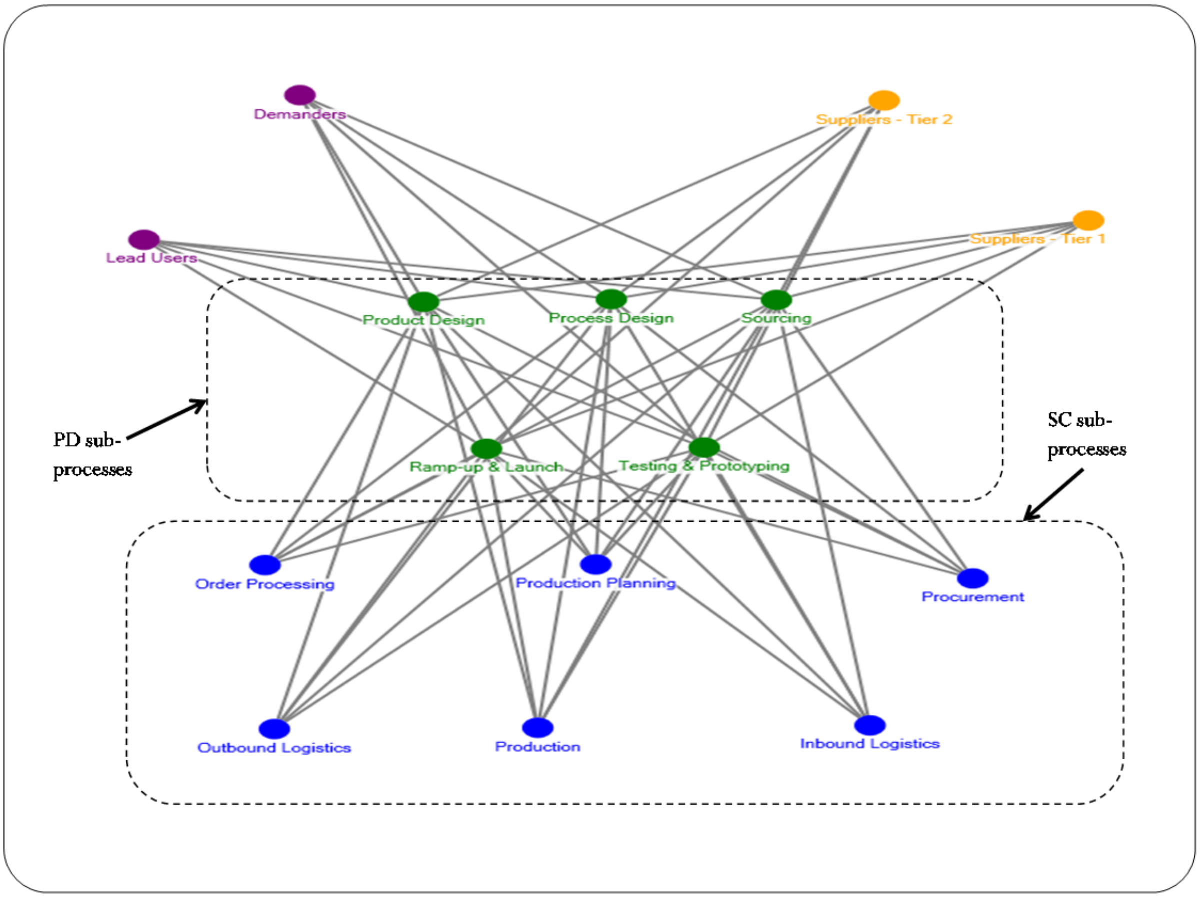


Figure 3.1 **Viable linkages between product development sub-processes and supply chain sub-processes during a PD project (Sub-processes are adopted from Figure 2.3, Chapter 2)**

In the next section, we discuss how the critical problem-solving inputs, information, knowledge and ideas can be mined and combined across the viable nodes in the network. Specifically, we review how *practice*, which we equate with sub-processes in action, context and non-human elements are important for effective exchanges of problem-solving inputs across domains. In addition, we carry forward the notion from this section that dyadic linkages, which operate in isolation, may not be the most effective way of generating and applying ideas, information and knowledge. Based on prior studies, we introduce the concept of *site* which adequately describes how multiple practices, people, non-human elements and context can be intertwined to effectively exchange and apply problem-solving inputs. As noted above, we also develop additional support for why we represent external nodes, customers and suppliers, through their processes.

3.4.2. Sharing and applying information, knowledge and ideas to solve PD problems

We concluded earlier that effective problem-solving between PD and the SC depends on the exchange of information, knowledge and ideas across domains, their sub-processes and even firm boundaries. Exchanges of problem-solving inputs across domains are therefore critical, but they are not trivial, for three main reasons. Firstly, the interpretation and application of information and ideas in different contexts requires knowledge (Ackoff, 1989). In principle, information can be codified and shared with relative ease. However, information can serve different purposes in different contexts. It can be reasoned that the same is true for ideas. Consider, for example, the PD problem of optimizing the product design. Incorporating ideas and information from suppliers into product design often happens in the context of optimizing the integration of supplier components and technologies. By contrast, collecting customer ideas and information for product design typically takes place in the context of evaluating and optimizing the market appeal of the product. Interpreting ideas and information in the first context requires technical knowledge, whilst the latter requires commercial knowledge. Ultimately, the inputs from both origins will have to be incorporated in the product and process design, which requires a deep understanding of why products function as they do and why processes work as they do (Wheelwright and Clark, 1992).

Secondly, drawing from knowledge across domains can be difficult, because much of it is embedded and thus tends to “stick” to practice (Von Hippel, 1994; Szulanski, 1996; Carlile, 2002, p.446; Tatikonda and Stock, 2003). Implied is that knowledge (and its complements information and ideas) that sticks to practice can be shared most effectively, when the practice or the process is actuated, such that it is emulated or executed by the people who are charged with its implementation. For example, knowledge is co-created and made accessible, while product designers meet with suppliers, production and procurement people to discuss the integration of a specific component and thereby emulate the procurement and assembly process.

Thirdly, in the process of sharing problem-solving inputs, non-human elements can play an important mediating role in problem-solving during PD. Particularly representations of the new product - like the product drawing/model in our example - and the processes (charts, maps, manufacturing drawings) are important mediators in PD (Pisano, 1996; Carlile, 2002, p.449).

In sum, we conclude that a linkage between PD and the SC is most effective in sharing and applying problem-solving inputs, when practice, people, context, as well as non-human elements are intertwined. Exactly this notion is adequately captured in the concept of a *site*. The concept of *site* has been described in detail by Nicolini (2010) in the context of a study of Telemedicine. Accordingly, *site* is the nexus of practice, the net of actions that connects people, mediating non-human elements (i.e. objects, like charts or Information Systems) and context. Nicolini (2010) demonstrates that the creation of a *site* is essential in sharing situated or embedded knowledge that enables a particular problem-solving activity, like remotely diagnosing a patient and subsequently providing health care services. Central to the notion of *site* is that knowledge and practice can be understood as a form of equivalence (Tsoukas 2005; Gherardi 2006), which Nicolini (2010) describes as *knowing*, implying that practice (activity) is essential in making knowing possible. Put another way, knowing comes from practice, much like the practice of riding a bike is necessary to obtain and improve the knowing of bike riding.

Another very important aspect of the concept of *site* (of knowing) is that it serves as a clearing, “similar to the idea of a forest clearing or a spotlight illuminating objects in a room” (Nicolini, 2010). Put in the context of our study, participating in the activity when a sub-process is emulated or executed makes knowledge, ideas and information better visible and accessible. Therefore, the illumination that *site* provides should help to discover vital problem-solving inputs, but also issues that deserve attention in the first place.

In order to illustrate the applicability of the concept of *site* as an appropriate theoretical and empirical lens in our context, consider a few linkages between PD sub-processes and external nodes that represent customer and supplier processes. Connecting PD with an emulation of purchase behavior of *demanders* could improve *process design* such that a flexible production process will be created for fluctuating demand or an efficient process for steady demand. Linking PD with the act of children playing with prototype toys as *lead users* could support the process of *product design,* as it helps the design team understand how the product will be used. Observing how *tier 1 suppliers* integrate their technology in other end products could help to optimize *product* and *process design*. Finally, emulating the procurement and delivery of *tier 2 supplier* components could benefit the effectiveness and efficiency of *sourcing (*of components during PD*), as well as launch and ramp-up* and therefore help to mitigate the turbulence of the launch period.

It is important to note that linkages between two or more sub-processes can operate at different degrees of intensity. For example, people from the supply chain and others from PD could attend meetings together or exchange emails to share superficial information. We argue that in order to effectively share and apply problem-solving inputs the people who are part of the sub-processes need to actively participate and be “in the site”. As an illustration, consider that one could read about riding a bike, watch a video about riding a bike, or get in the site and engage in the practice of riding a bike with someone who already knows how to ride a bike. For that reason, we introduce a measure that allows us to measure the intensity of linkages between sub-processes based on the degree of participation.

3.5. Exchange intensity and aggregate-level involvement

3.5.1. Construct for dyadic exchange intensity: Communication mode

According to the previous section, a more intense, participative linkage between two nodes improves the exchange of problem-solving enablers and thereby problem-solving performance related to the dyad. Kahn and Mentzer (1998) provide a useful definition to capture differences in the degree of participation or *exchange intensity* at the dyadic level based on communication modes: interaction, collaboration and a composite mode. Interaction relies on face-to-face meetings, memoranda, telephone conferencing and the exchange of standard documents. In the context of this study, interaction represents low exchange intensity. Collaboration, on the other hand, is based on shared goals, processes and resources. Shared resources create important boundary objects, which can be an important factor in sharing problem-solving inputs in PD (Carlile, 2002). Collaborative groups would view themselves as highly interdependent and involved, whilst interacting groups would be described as independent. Thus, a collaborative mode implies high exchange intensity. The composite mode represents a moderate middle ground between collaboration and interaction. In the empirical part of their study, Kahn and Mentzer (1998) established two constructs for interaction and collaboration modes, respectively. Both constructs were developed and tested to measure the communication and integration between Marketing, Manufacturing and R&D departments and its impact on performance. Among the dependent variables was product development performance. As a consequence, their constructs are applicable in our context and we define exchange intensity between two dyads in terms of communication modes that indicate the degree of participation.

3.5.2. Construct for aggregate-level involvement: Exchange intensity and timing

Up to this point we have examined exchange intensities at the dyadic level. Our discussion in Section 3.4.2 has indicated that more participative connections facilitate a better exchange of vital problem-solving inputs (information, knowledge and ideas). Thus, in general, and with a restricted view on one dyad, more exchange intensity appears to be better for problem-solving performance. However, we have also noted that at the aggregate level, many very intense linkages draw on resources and may come at the expense of longer problem-solving periods. Most PD projects are subject to constraints for resources and time. In addition, the overall problem-solving need may differ between one project and another. Time-to-market (meeting the window of opportunity for the product launch) may in some cases be more critical than presenting a perfect solution for processes and products. It therefore appears that when multiple linkages are activated, resource consumption and timing become more critical. For that reason, we define *aggregate-level involvement* between development and the supply chain as the total of the product of temporal overlap and exchange intensities for all of the (50) dyads in the network. Like Pisano (1996), we propose to capture timing via the the timeline of the PD project and the relative *temporal overlap* of each development sub-processes.

In the next two sections, we discuss and hypothesize the relationship between aggregate-level involvement and performance.

3.6. Problem-solving linkages and their impact on performance

3.6.1. Aggregate-level involvement and PD problem-solving performance: The problem of alignment between PD and the SC

We concluded earlier that recognizing and addressing interdependencies between PD and the SC is an important part of problem-solving during PD. Typically, not all of the problems encountered during PD projects involve many interdependencies across many sub-processes. Thus, for many smaller PD problems only one or few linkages may be relevant. However, in other cases problem-solving can benefit from multiple linkages, especially, when the problems' scope extends across the content of multiple sub-processes in both domains. At the extreme, it may require a connection across all 50 viable linkages. The purpose of this section is to discuss the effect of aggregate-level involvement on problem-solving performance relating to problems that require involvement from many sub-processes.

One critically important problem that creates interdependencies across all or most of the sub-processes in PD and the SC is the alignment of product and order fulfillment design (see Chapter 2 and 4) that relates to matching the choice of how the product is delivered with the appropriate product architecture (Olhager, 2003; Simchi-Levi, 2008). Chapter 4 discusses how *alignment* is created when an *open architecture* is matched with a *built-to-order (BTO) supply chain,* because the simplification of the product, enabled via an open architecture, supports the flexibility and responsiveness required when order fulfillment aims to build products to customers' requirements. Likewise, alignment is created when an *interdependent architecture* is matched with a *built-to-stock* (*BTS)* supply chain, because the order fulfillment system helps to preserve the product's integrity and maximize process efficiencies. The 2x2 matrix representing the four matching scenarios and the two that correspond to alignment (a match) is shown in Figure 3.2.

	BTO Supply Chain System	BTS Supply Chain System
Open Product Architecture	*match*	*mismatch*
Interdependent Product Architecture	*mismatch*	*match*

Figure 3.2 Alignment (match) between product design and supply chain design; adopted from Section 4.6.1 Chapter 4

Figure 3.2 suggests that the decision that creates alignment or misalignment can be straightforward at the strategic level. By contrast, the discussion in Chapter 4 and Section 3.7, where we discuss how alignment is measured, indicate that actualizing it at the sub-process level may be more involved. On the one hand, when a new supply chain for a radically new product needs to be established, ensuring alignment requires that the interdependencies among all sub-processes are well understood. Since such products have not been in the market before, every SC sub-process (e.g., inbound, production, and outbound logistics) must be carefully examined and recognized during each of the PD sub-processes. On the other hand, if the new product is a simple line extension (i.e. an incrementally new product) the supply chain may already exist. If alignment already exists, less aggregate-level involvement may be required. However, insufficient linkages at the sub-process level may have created misalignment in prior versions of the product. In that case, low aggregate level involvement increases the likelihood of not detecting and correcting misalignment. In sum, we expect that the accomplishment of alignment between supply chain design and product architecture, shown as matches in Figure 3.2, will correlate with higher aggregate-level involvement.

Hypothesis #1: The difference in aggregate-level involvement between the group of PD projects that resulted in alignment and the group of PD projects without alignment will be significant. The aggregate-level involvement will be higher for PD projects that resulted in alignment.

3.6.2. Aggregate-level involvement and product success

Prior literature recommends that indicators of success with new products measures should focus on profitability because “this is the ultimate performance indicator in management science” (Ernst, 2002). Perhaps for that reason it is more and more common practice to determine PD project success with return-based measures like the net present value (NPV) or the internal rate of return (IRR) (Kerzner, 2001; Ulrich and Eppinger, 2011). At the root of return-based success measures of PD projects are two distinct components: (1) pre-launch performance, which is based on the expenses for the development effort and (2) post-launch performance, which is representative of positive cash-flows that ought to recover the expenses for the PD project and eventually generate positive returns. Key determinants of pre-launch expenses are time-to-market and productivity, while post-launch earnings depend on revenue and the total cost to deliver the product to customers (Brown and Eisenhardt, 1995; Ulrich and Eppinger, 2011). Based on our earlier discussion, we expect aggregate-level involvement between PD and the SC to affect both pre-launch and post-launch performance, although its effect may not always be continuously positive across the viable range of aggregate-level involvement . For example, more linkages imply more *reach* for the vital inputs for problem-solving. Consequently, more critical interdependencies will be detected and addressed appropriately, supply chain processes should become more efficient, positively affect total supply chain cost and therefore bost post-launch performance. At the same time, however, higher aggregate-level involvement can have a negative effect on pre-launch performance, because it can lead to higher resource consumption and slower progress. Findings by Hansen (1999) at the intra-firm level and Uzzi (1997) at the inter-firm level of analysis suggest that operational success sometimes requires a reduction of operational intensity, in particular as task complexity decreases. A key reason for this may be that individuals and groups who are tightly linked and involved in intense exchanges experience more conflict situations and difficulty in finding consensus in decision-making processes, which results in a negative impact on productivity. Another reason might be that collaborative communication modes are associated with a high degree of interaction frequency, and therefore absorb a higher amount of resource time (Kahn and Mentzer, 1998). The effect of being less productive and slower could, of course, carry over into the post-launch period, because missing the window of opportunity for a new product launch can be very detrimental to its performance in the marketplace. Last, high aggregate-level involvement may not provide immediate results, because the willingness and ability to collaborate need to develop over time (Kahn and Mentzer, 1998). In other words, PD projects that were executed with a high degree of involvement in the network for the first time, might not realize as many gains as those that operated with long acquainted relationships.

In summary, we do not expect a continuously positive relationship between aggregate-level involvement and PD project success, because involvement that is too intense and maintained for too long will cause the development project to become unproductive and delayed such that pre-launch and post-launch performance are negatively affected. In a general sense, it is more likely that there is a level of involvement where the expenses begin to outweigh the benefits and the marginal effect on product success is negative. Finally, the aggregate-level problem solving need may be different between one PD project and another and thus, different degrees of aggregate-level involvement may be appropriate in different cases. As a consequence, we conjecture that product success will not correlate with higher aggregate-level involvement.

Hypothesis #2: The difference in aggregate-level involvement between the group of successful PD projects and unsuccessful PD projects will not be significant.

3.6.3. Critical linkages and groups of related linkages in the problem-solving network

Following the previous section, we note that firms need to be attentive to and selective about the degree of involvement between PD and the SC during development. Prior literature has noted that out of the viable linkages between PD and the SC, some may be more critical than others. Zacharia and Mentzer (2007) for example, suggested in their study of the linkage between logistics and PD that the role and value of linkages with logistics may be different across the sub-processes of PD. Accordingly, a viable path to mitigate the detrimental effects of excessive connections is to primarily focus on linkages or groups of linkages that are critical in a general sense, regardless of PD project or industry context.

Accordingly, we aim to identify the critical linkages, dyads between sub-processes, within the network of viable connections. We define linkages as critical when their exchange intensity is higher than and significantly different from the average exchange intensities originating from both its connecting sub-processes. For example, each linkage that terminates in *product design* will be compared to the average exchange intensity of ten linkages that terminate in *product design*. Because every linkage has two connecting sub-processes, its exchange intensity will be compared to the average exchange intensity of both sub-processes. In sum, we conjecture that within the network of 50 viable connections, critical linkages exist.

> *Hypothesis #3: Critical dyadic linkages exist in the network of 50 viable connections with an exchange intensity that is higher than and significantly different from the average exchange intensities of its corresponding sub-processes.*

Whilst critical linkages should exist, they may not operate in isolation. For example, our discussion earlier has shown that *product design* may form beneficial linkages with *logistics* (Ibid, p.10), as well as *suppliers* and *customers* (Ibid, p.8) to optimize product performance. Accordingly, we have noted that a problem-solving *site* may connect more than two sub-processes at a time. It is implied that effective problem-solving during PD may require more complex configurations than just dyadic linkages between PD and SC sub-processes. As a consequence, critical dyadic linkages should not be independent and we expect to find the presence of three-way and multi-way linkages that form *complex problem-solving sites*. The interdependence between groups of critical dyadic linkages is indicated by high and significant levels of correlation between critical dyadic linkages across PD projects.

Hypothesis #4: The critical dyadic linkages between PD and the SC are not independent and problem-solving sites with multiple correlated linkages exist.

3.6.4. Complex problem-solving sites and success with new products

Up to this point, we have argued that effective problem-solving requires more than one or more isolated dyadic linkages. We also conjectured that at the other end of the spectrum, involvement across too many linkages (on the aggregate) can be detrimental for PD project success. A viable course of action is then to focus on specific problem-solving *sites* that are indicated by correlated dyadic linkages. Clearly, if *sites* consist of multiple linkages that exhibit higher and different exchange intensities across a variety of PD projects, then their connection should matter for PD project success, regardless of project context. In addition, if sites consist of linkages that correlate across a variety of PD projects, then their effectiveness should depend on the interplay of the bundle that is the site rather than each linkage by itself. Similar to our approach with aggregate-level involvement, we include both exchange intensity and temporal overlap when we consider *site* involvement and hypothesize the impact of complex problem-solving sites on PD project success.

Hypothesis #5: The effect of more involvement (higher exchange intensity and timing) in complex problem-solving sites on PD project success with new products will be significant and positive.

It is worth noting contrast between hypothesis #2 and hypothesis #5. On the one hand, we argued that more aggregate-level involvement is not always better. On the other, we also conjecture that more involvement on specific bundles of critical linkages that are sites will be beneficial to success. This distinction highlights the importance of examining the linkages between PD and the SC at the more refined level of sub-processes.

3.7. Methods

3.7.1. Data sources and data collection

A survey design was used to collect the data for this research. The final survey design was based on a careful review of prior empirical literature in this area, informal exchanges with experienced practitioners in the area of new product introduction and a pilot test of an initial survey which included a group of ten product managers.

Each observation corresponds to one product development project. In our invitation to the survey, we asked the participants to report on products that were launched within the last 5 years (2007-2012). We also informed potential respondents that we are looking for a balance between unsuccessful and successful new products, and thereby encouraged them not to select only their best PD projects.

We contacted and recruited participants from our personal professional networks, through the membership of a large U.S - based supply chain management association and through professional networking services (PNS). We primarily contacted individuals whose professional profile indicated that they had recently been involved in either new product development or new product introduction and who had responsibilities that related to the supply chain for new products. A total of 3,130 individuals were contacted as lead respondents, primarily via email and phone, out of which approximately 300 indicated an initial interest in participating. Out of this group, 141 surveys were returned via an online data collection platform. Most non-respondents indicated that they were prohibited from participating either because of insufficient data and records about their PD projects or because of lack of time and resources. 87 surveys were not considered, because they did not return one or more of the key variables of this study, which left a final sample of 54 responses that were included in or analysis. After an initial review of our survey items, most respondents indicated that because of the cross-functional nature and depth of our questions, they had to first collect the project data by accessing project records or holding meetings with project team members. The fact that most, if not all responses, are based on the company's project records or on input from multiple project team members should have contributed to mitigate the problematic effects of single methods, or single-response bias in empirical PD research (Ernst, 2002).

3.7.2. Measurements and variables

Like Kahn and Mentzer (1998), we use a 5-point scale to measure communication modes as a proxy for exchange intensity between two nodes. As noted before, we see people as a fundamental part of the process and therefore the communication mode applies to how the people interact. We apply Kahn and Mentzer's constructs and their factors in our tests to describe the anchors of our scale for the communication mode.

Like Pisano (1996), we measure temporal overlap of each PD sub-process, using a *temporal overlap index*. The overlap index for a PD sub-process is high (1 or 100%) when a sub-process starts close to the beginning of the project. Conversely, it is close to the lowest (0 or 0%) when a sub-process started close to the completion of the PD project. Because PD efforts are typically highly iterative, our premise is that all five sub-processes of PD will not be fully completed until the product is launched (Braha and Bar-Yam, 2004). In other words, the duration of each dyadic linkage is represented by the time between the start of its corresponding PD sub-process and the time of launch. The temporal overlap for each PD sub-process is calculated as a fraction (percentage) of the total duration of the PD project. In this manner, a scaled timeline can be derived for each PD project. Thus, for the computation of aggregate-level involvement, we will first multiply the exchange intensity of each dyad with the temporal overlap of its PD sub-process. The final measure for aggregate-level involvement will then be derived by totaling the scores obtained from the previous step for the 50 dyads in the network.

Product success was measured as a dichotomous variable. The respondents were asked to report whether the PD project was successful, because the financial results met or exceeded expectations from the time of launch at the post-launch review (success) or was unsuccessful, because it did not meet the expectations (no success). By selecting the point of reference for the financial expectations at the time of product launch, we suppressed the effects of overly optimistic estimates for product success (NPV) that are typical prior to launch.

The variable for *alignment* between supply chain design and product architecture was also dichotomous. We presented typologies described by Olhager (2003) and Simchi-Levy et al (2008) to allow the respondents to identify the supply chain design for each PD project. Based on their selection, the supply chain was classified as a *BTS* or a *BTO* system as discussed in Chapter 4. In addition, the respondents characterized the product architecture based on frameworks proposed by Ulrich (1995) and Fixson (2005). We classified the product architecture as an open or a coupled architecture as discussed in Chapter 4. Alignment was determined in accordance with Figure 3.2.

The exchange intensities for a network of 50 linkages were reported by the respondents. For this purpose, each respondent was presented with a 5x10 matrix, indicating 5 sub-processes in the PD domain an 10 sub-processes in the SC domain. The respondents were prompted to enter 0 for pairs with no connection and the level of exchange intensity between 1 and 5 for pairs that were connected. In order to establish a scaled timeline for each PD project, the respondents were asked to report the total duration of the project and the starting point of each PD sub-process. Using the scaled timeline for the project and the dyadic exchange intensities in the matrix, aggregate-level involvement was then computed as described in Section 3.5.2. An example matrix is shown in Appendix 3.C.

We control for whether market conditions have changed significantly in the assessed period through a measure of munificence (MUNI) (Edelmann and Yli-Renko, 2008). Based on prior work by Dean (1995), Dess and Beard (1984) and Bamford, Dean and McDougall (2000), changes in munificence will be calculated for a five year period around the launch of the new product. The change in munificence for the product in question will be calculated based on industry shipments (extracted from the annual survey of manufacturers: ASM).

3.7.3. Sample demographics and PD project data

The sample includes 54 PD projects from a wide range of industries. Among them are development projects for new toys, consumer electronics, medical devices, automotive products, micro-electronics and industrial machinery (A list of NAICS codes of all products is shown in Appendix B). The majority of participating firms can be classified as large size enterprises[6], because they had more than 500

---

[6] Based on OECD criteria for firm size classification

employees (59.3%) and revenues above $50M per annum (75.9%). Table 3.1 indicates that the largest fraction of PD projects had team sizes between 6 and 10 members (44.2%).

		SC people involved during PD				
		Less than 2 people	Between 3 and 5 people	Between 6 and 10 people	More than 10 people	Total
PD Team Size	Less than 5 people	11.5%	3.8%	0.0%	1.9%	17.3%
	Between 6 and 10 people	13.5%	25.0%	1.9%	3.8%	44.2%
	Between 11 and 15 people	3.8%	7.7%	1.9%	0.0%	13.5%
	More than 15 people	0.0%	7.7%	9.6%	7.7%	25.0%
Total		28.8%	44.2%	13.5%	13.5%	100.0%

Table 3.1 Cross-tabulation of Project Development (PD) team size and number of participants from the Supply Chain (SC)

The largest fraction of PD projects with respect to involvement from the SC domain was between 3 and 5 SC people participating (44.2%). The mean success rate of participating firms with all of their new products was 65.9% (N=43, Std. Dev. = 25.43), which is in line with previously reported figures (Cooper, 2005; Crawford and Di Benedetto, 2008) and therefore indicates representativeness of the sample. Some of the firms did not report typical success rates with their PD projects because of concerns with confidentiality.

The fraction of successful PD projects within our sample was 52.9%. The majority of the new products in the sample were launched after 2010 (54.7%), and 98.1% were launched after 2007, which satisfied our requirement for a launch time within the past five years. The average PD project duration was 26.71 months (Range: 4 to 84 months; Std. Dev. = 19.74 months). The mean temporal overlap was greatest for the PD sub-process product design (0.89; Std. Dev. =0.13), followed by process design (0.70; Std. Dev. =0.24), sourcing (0.67; Std. Dev. =0.23), prototyping & testing (0.66; Std. Dev. =0.25) and launch & ramp-up (0.21; Std. Dev. =0.24). The ranking of means for temporal overlap of the five PD sub-processes in our sample aligns with our expectation in terms of precedence between the PD sub-processes (see Chapter 2).

3.8. Analyses, Results and Discussion

As a pre-test for and an assessment of the validity of the entries in the matrix of linkages, we tested the correlation between the calculated aggregate-level communication mode (without temporal overlap included) with a single measure overall communication mode from our respondents and found that they were significantly correlated (N=54; Pearson Correlation = 0.305; SIG.<0.05 (0.025).

3.8.1. The effects of aggregate-level involvement

In order to test hypothesis 1, we compared the standardized (Z-scores) mean aggregate-level involvement for the independent samples of PD projects that resulted in *alignment* and PD projects that did not accomplish *alignment*. Likewise, for hypothesis 2, we compared the standardized (Z-scores) mean aggregate-level involvement for the independent samples of successful PD projects and unsuccessful PD projects. For both tests, we conducted univariate analysis of variance (ANOVA). All the assumptions for univariate analysis of variance were satisfied (Table 3.2). The results in Table 3.2 show that the aggregate-level involvement between the PD domain and the SC domain was significantly different for the PD projects that accomplished alignment from the PD projects that did not.

	Mean (Aligned)	Mean (Not Aligned)	F-statistic	SIG.
Aggregate-Level Involvement (1),(2),(3)	0.544	-0.212	6.4104	0.0147*

Notes: * significant at p<0.05

(1) Levene's test confirmed equality of error variances across groups (SIG.=0.624)
(2) Values for Aggregate-Level Involvement are normally distributed
(3) Mean values are standardized (z- scores)

Table 3.2 ANOVA results for the test of aggregate-level involvement of the groups of PD projects with and without alignment

In addition, the mean aggregate-level involvement was higher for PD projects that achieved downstream alignment. Consequently, hypothesis 1 is supported.

The results from an ANOVA test of hypothesis 2 confirmed that we cannot reject the null-hypothesis of the test (Table 3.3). However, the design of the ANOVA does not allow us to reject the alternative hypothesis and accept the null-hypothesis of the test[7]. Therefore, solely based on the ANOVA results, we cannot conclude that there is no difference in aggregate-level involvement between the groups of successful and unsuccessful PD projects. In order to strengthen our support, we conducted a power analysis with a power level of 0.8, a sample size of 54 and a significance level of 0.95 (alpha = 0.05) to determine the required difference to reject hypothesis 2. The actual difference (0.200) between aggregate level exchange intensities is 22.2% of the difference required to reject the null hypothesis of the ANOVA and thereby hypothesis 2 (0.899). In order to reject hypothesis 2 at a difference between means of 0.2, a sample size of 1053 observations would be required. Because the fraction of the actual difference is low and the hypothetical sample size is excessively high, we conclude that the probability of committing a type II error (not rejecting the null hypothesis of the ANOVA when it is false) is low and there is adequate analytical support for hypothesis 2.

	Mean (Success)	Mean (No Success)	F-statistic	SIG.
Aggregate-Level Involvement (1),(2),(3),(4),(5)	0.096	-0.104	0.4899	0.4873

Notes: * significant at $p<0.05$

1. Levene's test confirmed equality of error variances across groups (SIG.=0.939)
2. Values for Aggregate-Level Involvement are normally distributed
3. Actual difference between means is 0.200
4. Difference to detect at N=54, alpha=0.95 and 1-beta=0.8 is 0.899
5. Mean values are standardized (z-scores)

Table 3.3 ANOVA results for the test of aggregate-level involvement of the groups of PD projects with and without product success

---

[7] The null hypothesis in an ANOVA states that there is no difference between the means of levels

3.8.2. Dyadic level exchange intensities, critical linkages and sites

Because the exchange intensities of dyadic linkages in the network are not independent, our tests for hypothesis 3 are based on non-parametric analysis (Friedman test) for k-related samples. As described earlier, each node in the PD domain can potentially connect to 10 (sub-processes) nodes in the SC domain. Conversely, each (sub-process) node in the SC domain can potentially connect to 5 (sub-processes) nodes in the PD domain. The two points of reference for the identification of linkages of high exchange intensities as per hypothesis 3 are the average exchange intensities for its connecting sub-processes. Expressed in network terminology, we identify a critical arc in the network through comparisons with both its nodes. We conduct our analysis in three steps: First, we apply a global test which compares the average for each sub-process with all of its linkages in order to identify, if at least one of them is different (H0: none of the linkage means is different from the average of the node). Next, we compare the exchange intensity of each linkage with the exchange intensity of its corresponding sub-process in the PD domain and test for a significance in the difference. Last, we compare the exchange intensity of each linkage with the exchange intensity of its corresponding sub-process in the SC domain and test for a significance in the difference. For example, the exchange intensity of the linkage between order processing and product design (mean = 0.70) is first compared to the exchange intensity that is computed for each observation for order processing (mean = 1.47) and then compared to the exchange intensity that is computed for each observation for product design (mean = 1.74). A linkage is identified as critical only when its exchange intensity is higher and different than the computed values for both its nodes.

The results shown in Table 3.4 indicate that the exchange intensities for five linkages are different from the average exchange intensities of their nodes and higher. As noted in Table 3.4, the significance levels were adjusted for multiple tests using Bonferroni-correction. The critical linkages (PD node mentioned first) and therefore dyadic problem-solving sites are product design and lead users (2.89), development sourcing and procurement (3.50), development sourcing and suppliers – tier 1 (3.16), ramp-

		Paired k-related test at 0.01 SIG. level (Note 1)									
	Mean	Product Design		Process Design		Development Sourcing		Testing & Protoyping		RampUp&Launch	
			SIG.		SIG.		SIG.		SIG.		SIG.
Order Processing	1.47	0.70	0.000	1.43	0.132	1.26	0.005	1.17	0.003	2.80†	0.000
Production Planning	2.36	1.52	0.000	2.46	0.555	2.46	0.376	2.04	0.149	3.30**	0.000
Procurement	2.57	1.91	0.000	2.46	0.101	3.50**	0.000	2.06	0.001	2.93	0.170
Inbound Logistics & Warehousing	1.52	0.54	0.000	1.57	0.869	1.70	0.398	0.98	0.000	2.81†	0.000
Production	2.80	2.37	0.083	2.83	0.879	2.43	0.008	2.81	0.189	3.57**	0.000
Outbound Logistics & Distribution	1.50	0.96	0.001	1.48	0.217	1.13	0.002	1.11	0.004	2.83†	0.000
Suppliers - Tier 1	2.84	2.85	0.423	2.54	0.078	3.16**	0.003	2.87	0.876	2.80	0.262
Suppliers - Tier 2	1.64	1.24	0.001	1.41	0.009	2.15†	0.000	1.63	1.000	1.78	0.139
Demanders	1.88	2.37†	0.000	1.39	0.000	1.00	0.000	2.02	0.160	2.61†	0.000
Lead Users	2.23	2.89**	0.001	1.70	0.001	1.06	0.000	2.74†	0.006	2.78†	0.004

	Paired k-related test at 0.005 SIG. level (Note 2)									
	Product Design		Process Design		Development Sourcing		Testing & Protoyping		RampUp&Launch	
Mean	1.74		1.93		1.99		1.94		2.82	
		SIG.		SIG.		SIG.		SIG.		SIG.
Order Processing	0.70	0.000	1.43	0.005	1.26	0.000	1.17	0.000	2.80	0.396
Production Planning	1.52	0.083	2.46	0.011	2.46	0.005	2.04	1.000	3.30**	0.000
Procurement	1.91	0.199	2.46†	0.000	3.50**	0.000	2.06	0.886	2.93	0.123
Inbound Logistics & Warehousing	0.54	0.000	1.57	0.017	1.70	0.011	0.98	0.000	2.81	1.000
Production	2.37†	0.000	2.83†	0.000	2.43	0.063	2.81†	0.001	3.57**	0.000
Outbound Logistics & Distribution	0.96	0.000	1.48	0.008	1.13	0.000	1.11	0.000	2.83	1.000
Suppliers - Tier 1	2.85†	0.000	2.54	0.036	3.16**	0.000	2.87†	0.001	2.80	0.886
Suppliers - Tier 2	1.24	0.002	1.41	0.001	2.15	0.579	1.63	0.149	1.78	0.000
Demanders	2.37	0.005	1.39	0.017	1.00	0.000	2.02	0.889	2.61	0.889
Lead Users	2.89**	0.000	1.70	0.484	1.06	0.000	2.74	0.008	2.78	0.327

Notes:

** Value is different from and higher than the two corresponding nodes

† Value is different from and higher than one of the two corresponding nodes

1) Significance level was adjusted through Bonferoni correction for five tests against the node mean

2) Significance level was adjusted through Bonferoni correction for ten tests against the node mean

Table 3.4 Results of nonparametric comparison of means in the 10x5 matrix against the averages of the 15 nodes

up & launch and production planning (3.30) as well as ramp-up & launch and production (3.57). As a consequence, hypothesis 3 is supported.

Our findings of critical dyadic linkages are adequately supported by prior research. For example, the criticality of the connection between *development sourcing* and *procurement* confirms the conclusions by Schiele (2010) who noted that the purchasing function nowadays assumes a dual role that is to support the process of innovation and maintaining cost and supplier integration over the product life-cycle. Furthermore, the presence of two critical linkages with *launch and ramp-up* confirm prior conclusions by Calantone, Di Benedetto and Stank (2005) who noted the criticality of planning and producing new products in the turbulence of the launch-phase in PD. Moreover, the critical linkage between *tier 1 suppliers* and *development sourcing* emphasizes the importance of the technology supply chain as discussed by Tatikonda and Stock (2003). In accordance with Schiele (2010), we suggest that *sourcing* typically assumes a central in integrating *suppliers* into the entire development effort and therefore mediates the exchanges between suppliers and other product development sub-processes, especially at the beginning of the PD project. Finally, the presence of a critical linkage between *lead users* and *product design* confirms findings by Thomke and von Hippel (2002).

The tests for hypotheses 4, which postulates the presence of complex problem-solving sites, were based on correlation analysis and ensuing exploratory factor analysis (principle component analysis). The five critical linkages identified in Table 3.4 were used to derive factors based on their correlations and common variance. Quartimax orthogonal rotation was used to simplify the factor loading matrix (Hair, Black, Babin, Anderson, 2010). The rotated factor loading matrix and the results from the verification test for the basic assumptions of principle component analysis are summarized in Table 3.5.

Dyadic Exchange Intensity between…	Factor 1 (internal site)	Factor 2 (external site)
Production planning and *launch & ramp-up*	**0.906**	-0.041
Procurement and *development sourcing*	**0.847**	0.261
Production and *launch & ramp-up*	**0.810**	0.378
Lead users and *product design*	0.391	**0.730**
Suppliers - tier 1 and *development sourcing*	0.208	**0.858**

Notes:

1. *77% of total variance extracted*
2. *Measure of Sampling Adequacy (MSA) > 0.5 (0.801 KMO)*
3. *Bartlett's test of sphericity: SIG.<0.05 (0.000)*

Table 3.5 Results of correlation and principle component analysis for five critical dyadic linkages

As illustrated in Table 3.5, all assumptions for principle component analysis were satisfied, 77% of the total variance was extracted as two factors were derived. Accordingly, hypothesis 4 is supported. Factor 1 had high loadings from the linkages between *production planning* and *launch & ramp-up*, *procurement* and *development sourcing*, as well as *production* and *launch & ramp-up*. Factor 2 had high loadings from the linkages between *lead users* and *product design* as well as *development sourcing* and *tier 1 suppliers*. Because Factor 1 is exclusively comprised of linkages between internal sub-processes, we named this complex problem-solving site *internal site* and because Factor 2 is comprised of two linkages between PD, customers and suppliers, we named it *external site*.

We tested hypothesis 5 based on our identification of the above two types of complex problem-solving sites that bundle critical linkages (one external and another internal). Accordingly, our model has two key independent variables that are both represented by the standardized values for their factor – one for the exchange intensities of the *external site* and another for the exchange intensities of the *internal site*. It is important to note that the earliest the *internal site* can be actuated in its entirety is when all sub-processes involved have commenced. Thus, the *internal site* is "brought fully to life" only when the *launch & ramp-up* sub-process has started. Prior literature suggests that thorough planning of the *launch*

& ramp-up sub-process is more beneficial to PD project success than any ad-hoc approach (Nagle, 2005). As a consequence, we expect timing to be critical for the *internal site* and therefore included the temporal overlap for *launch & ramp-up* in the model as an interaction effect. By contrast, we expect the *external site* to emerge in the very early stages of the PD project by default.

Furthermore and as discussed above, we expect the linkage between *suppliers – tier 1* and development *sourcing* to have a strong mediating function, through which *suppliers – tier 1* are connected to other PD sub-processes, even before the act of sourcing begins formally. Because product design has the highest temporal overlap (0.89) with a narrow standard deviation (0.13) [recall demographic data in section 3.7.3] the linkage between *lead users* and *product design*, will materialize almost from the beginning of the PD project in most cases. Moreover, connections between PD teams and lead users typically tend to emerge informally during the ideation phase, even before the development project is approved for execution (Barczak et al, 2009). As discussed earlier, we include environmental munificence (MUNI) as an important exogenous variable. Thus, our model for the test of hypothesis 5 is as follows:

$$\boldsymbol{Success^* = \beta_0 + \beta_1 \; x \; (Internal\ Site) + \beta_2 \; x \; (External\ Site) + \beta_3 \; x \; (Internal\ Site\ x\ Overlap\_Launch\&RampUp) + \beta_4 \; x \; (MUNI)}$$

with Success*= ln (Success/(1-Success)) and Success representing the probability that the NPV target was met or exceeded in the post-launch review. The impact of each variable is expressed through β_i. Its value translates one unit increase of the variable in percent change in odds to meet or exceed the NPV target as $e^{\beta i} - 1$.

The results, shown in Table 3.6 indicate that the model fit is appropriate, based on the Chi-square statistic of the reduction in Log-Likelihood. Furthermore, the parameter estimates confirm that the impact of the exchange intensity of the external site on PD project success was significant and positive. The effect of the exchange intensity of the internal site was not significant by itself, however, the interaction effect between the exchange intensity of the internal site and the temporal overlap for launch & ramp-up was significant and positive. Interestingly, the effect of MUNI was significant and negative, suggesting that less market munificence correlates with a higher probability of PD project success. This result may appear contradictory to contemporary models of PD success factors, however, one way of interpreting this result is that in a climate of economic downturn and for a limited period of time the introduction of new products can be an effective antidote to decline in an industry.

	Parameter Estimate	SIG.
Intercept	0.399	0.399
External Site	2.510	0.011*
Internal Site	-1.562	0.052
Internal Site x Overlap Launch & Ramp-up	3.840	0.034*
MUNI	-1.855	0.005*
Notes: *Significant at $p<0.05$ Model Test: ChiSquare (-2LL) = 32.89; SIG <0.0001; Nagelkerke Pseudo RSquare = 0.617; Specificity = 83.3%; Sensitivity = 76.9%		

Table 3.6 Results of binary logistic regression of problem-solving sites, timing and munificence on product success

The parameter estimates in Table 3.6 can be interpreted such that an increase in one unit on the standardized scale of the variable for the external site will raise the probability of product success by 92 percent[8]. Likewise, an increase in one unit on the standardized scale of the variable for the interaction effect of internal site and overlap launch & ramp-up will raise the probability of product success by 98 percent[9]. Expressed in terms of actionable managerial intervention, an increase of one unit on the standardized scale of the variable for the external site can, for example, be accomplished by simultaneously raising the exchange intensity between lead users & product design by 1.04 levels, as well as the exchange intensity between suppliers – tier 1 & development sourcing by 1.18 levels towards a

---

[8] The change in odds of success is $e^{2.51} - 1 = 11.30$; The change in probability of success is $(11.30/(11.30+1)) \times 100\% = 92\%$

[9] The change in odds of success is $e^{3.84} - 1 = 45.53$; The change in probability of success is $(45.53/(45.53+1)) \times 100\% = 98\%$

collaborative mode of communication (detailed calculations are presented in appendix A). An increase of one unit on the standardized scale of the variable for the internal site can, for example be accomplished by raising the exchange intensities of each of the site's three linkages by 1 level each towards a collaborative mode of communication and simultaneously increasing the temporal overlap of launch & ramp-up by 0.637 or 63.7% (detailed calculations are presented in appendix A).

3.9. Limitations

The broad range of industries represented in this study (reference Appendix B) suggests that the results are generalizable across many product development contexts. One limitation of the study is that we have not tested and verified the relationship between participative linkages, problem-solving-performance and success with new products directly in a longitudinal design for each of the viable linkages. We have inferred this causal path from a review and synthesis of prior literature that has examined many but not all of the viable linkages in this manner. Further, because the data is collected with a survey design, there is a risk of subjective and single-response bias (Ernst, 2002). Based on conversations with our participants during the data collection period, we expect that this effect has been mitigated to a large extent by the depth and complexity of our survey design. We learned that many, if not all of them, had to consult project records and multiple team members before they were ready to submit their responses. Finally, we expect that we have added sufficient rigidity to the definition of product success by asking respondents to report whether the financial forecasts from the time of launch have been met or exceeded at the post-launch review. First of all, financial planning for new products that includes generation of forecasts at time of launch and a comparison with actuals during a post-launch review is standard practice in larger firms. Secondly, the products in our sample have already been introduced to the marketplace and, thus, there is no incentive to justify project continuation or resource allocation with overly optimistic financial forecasts. Based on that premise, accurate records should be available and respondents have little to gain from reporting their perception rather than facts.

3.10. Implications for Management and Research

In this study, we have assessed multiple linkages between PD and the supply chain quantitatively and comparatively. One key contribution of this chapter is that we have conceptualized the connection between PD and the SC as a problem-solving enabler during development, which is comprised of a network of sub-processes. Based on a review of prior literature, specifically the idea of a *site*, we were able to theorize about and support the notion of complex, multi-way problem-solving linkages at the sub-process level. In the empirical part, we have confirmed that higher aggregate-level involvement between the domains will increase the likelihood of solving a particular kind of development problem with a large scope that pertains to multiple interdependencies across the domains of PD and the SC. At the same time, we were able to confirm that higher aggregate-level involvement will not necessarily lead to product success. Based on prior observations (Uzzi, 1997; Hansen, 1999), the relationship between aggregate-level involvement and the likelihood of product success may exhibit a maximum of net gains across the spectrum of aggregate-level involvement. Confirming the exact shape of the relationship between aggregate-level involvement and the likelihood of product success across the range of involvement would be a valuable ally for future research. It needs to be cautioned though that a cost-benefit analysis of this kind may be constrained by the accessibility of detailed financial records of PD projects and the required sample size. Another possibility is that the effectiveness of more aggregate-level involvement is contingent on contextual variables, such as product complexity (see Chapter 2).

In a sample of 54 PD projects, we have identified five linkages between *production planning* and *launch & ramp-up*, *procurement* and *development sourcing*, *production* and *launch & ramp-up*, *lead users* and *product design,* as well as *development sourcing* and *tier 1 suppliers* as critical. We have also confirmed that the five critical linkages operate in groups of two complex problem-solving *sites*. We have quantified how managers can increase the likelihood of product success by adjusting the exchange intensity of the five critical linkages and the temporal overlap of *launch & ramp-up*. However, the five critical linkages and their sites should be understood as a “must-have” configuration. Most likely, they are not sufficient by themselves to succeed with new products. In other words, we expect that the problem-solving *sites* we identified need to be augmented with other linkages based on the development context. For example, for products where logistics processes play an important part in maintaining product integrity and satisfying customers, a *site* with connections between *product design*, *process design*, *inbound* and *outbound logistics* may be highly advantageous. Moreover, cases like Inditex and their Zara brand, who compete with a high product introduction frequency, indicate how involved linkages between *order processing*, *procurement*, *product design* and *testing&prototyping* can be essential to realizing a strategy that is based on rapid product introduction.

In general, we hope that this study provides an appropriate platform upon which more empirical tests will be conducted on the same methodological basis. As recommended in Chapter 2, and as suggested above, future research in this area should include product complexity as an important contextual variable and organizational complexity as a further network parameter. However, it needs to be cautioned that the inclusion of those two variables will most likely necessitate substantial sample sizes to obtain sufficient and representative distribution across the spectrum of organizational complexity and product complexity. We also hope that this study will motivate future work with longitudinal designs for problem-solving linkages between PD and the SC, which prior research has not examined in that way.

References

Ackoff, R.L. 1989. From data to wisdom. ***Journal of Applied Systems Analysis***, Vol. 16, p. 3-9

Atuahene-Gima, K. 2003. The effects of centrifugal and centripetal forces on product development speed and quality: How does problem solving matter? ***The Academy of Management Journal***, 46(3): 359-373.

Bamford, C. E., Dean, T. J., & McDougall, P. P. 2000. An examination of the impact of initial founding conditions and decisions upon the performance of new bank start-ups. ***Journal of Business Venturing***, 15(3): 253-277.

Barczak, G., Griffin, A., & Kahn, K. B. 2009. Perspective: Trends and drivers of success in NPD practices: Results of the 2003 PDMA best practices study. ***Journal of Product Innovation Management,*** 26: 3-23.

Braha, D., & Bar-Yam, Y. 2004. The Topology of Large-Scale Engineering Problem-Solving Networks. ***Physical Review*** E 69, 016113, 2004

Brown, S. L., & Eisenhardt, K. M. 1995. Product development: past research, present findings, and future directions. ***Academy of Management Review***, 20(2): 343-378.

Calantone, R.J., Di Benedetto, A., Stank, T.P. 2005. Managing the supply chain implications of launch. ***The PDMA Handbook of New Product Development 2nd edition***. 2005. New Jersey: John Wiley & Sons

Carlile, P. R. 2002. A pragmatic view of knowledge and boundaries: Boundary objects in new product development. ***Organization Science,*** 13(4): 442–455.

Clark, K. B., & Fujimoto, T. 1991. ***Product development performance: Strategy, organization and management in the world auto industry***. Boston: HBS Press.

Cooper, R.G. 2005. New products – what separates the winners from the losers and what drives success. ***The PDMA Handbook of New Product Development 2nd edition***. 2005. New Jersey: John Wiley & Sons

Crawford, M., & Di Benedetto, A. 2008. ***New products management***. New York: McGraw-Hill. – database says date is 2003

Croom, S., Romano, P., & Giannakis, M. 2000. Supply chain management: An analytical framework for critical literature review. ***European Journal of Purchasing & Supply Management,*** 6: 67-83.

Croxton, K. L. 2003. The order fulfillment process. ***The International Journal of Logistics Management***, 14(1): 19-33.

Dean, T. J. 1995. ***New venture formations in United States Manufacturing: The role of industry environments***. New York: Garland Publishing.

Dess, G. G., & Beard, D. W. 1984. Dimensions of organizational task environments. ***Administrative Science Quarterly***, 29(1): 52-73.

Dougherty, D. 2007. Trapped in the 20th century? Why models of organizational learning, knowledge, and capabilities do not fit bio-pharmaceuticals, and what to do about that. ***Management Learning***, 38(3): 265-70.

Edelmann, L., & Yli-Renko, H. 2010. The impact of environment and entrepreneurial perceptions on venture-creation efforts: Bridging the discovery and creation views of entrepreneurship. ***Entrepreneurship Theory and Practice***, 34(5): 833–856.

Ernst, H. 2002. Success factors of new product development: A review of the empirical literature. ***International Journal of Management Reviews***, 4(1): 1-40.

Fixson, S. K. 2005. Product architecture assessment: A tool to link product, process and supply chain decisions. ***Journal of Operations Management***, 23: 345-369.

Forza, C., Salvador, F., & Rungtusanatham, M. 2005. Coordinating product design, process design, and supply chain design decisions. Part B. Coordinating approaches, trade-offs, and future research directions. ***Journal of Operations Management***, 23: 319-324.

Gherardi, S. 2006. ***Organizational knowledge - The texture of workplace learning***. Oxford, UK: Blackwell.

Hair, J., & Black, W. 2006. ***Multivariate data analysis***. NJ: Prentice Hall. – database has different dates with different cities.

Hansen, M. T. 1999. The search-transfer problem: The role of weak ties in sharing knowledge across organizational subunits. ***Administrative Science Quarterly***, 44(1): 82.

Hult, G. T. M., & Swan, K. S. 2003. A research agenda for the nexus of product development and supply chain management processes. ***Journal of Product Innovation Management***, 20(5): 333-336.

Iansiti, M., & Clark, K. B. 1994. Integration and dynamic capability: Evidence from product development in automobiles and mainframe computers. ***Industrial and Corporate Change,*** 3: 557-606.

Kahn, K. B., & Mentzer, T. J. 1998. Marketing's integration with other departments. ***Journal of Business Research***, 42: 53-62.

Kerzner, H. 2001. ***Project management: A systems approach to planning, scheduling, and controlling***. Hoboken, NJ: John Wiley & Sons.

Krishnan, V. & Ulrich, K. T. 2001. Product development decisions: A review of the literature. ***Management Science*****,** 47(1): 1-21.

Lambert, D. M. & Cooper, M. C. 2000. Issues in supply chain management. ***Industrial Marketing Management***. 29(1): 65-83.

Lau, A. K. W., Yam, R. C. M., & Tang, E. 2007. The impacts of product modularity on competitive capabilities and performance: An empirical study. ***International Journal of Production Economics,*** 105(1): 1-20.

Nagle, S. 2005. Managing new product and service launch. ***The PDMA Handbook of New Product Development 2nd edition***. 2005. New Jersey: John Wiley & Sons

Nahapiet, J., Ghoshal, S. 1998. Social capital, intellectual capital and the organizational advantage. ***The Academy of Management Review***, 23 (2)

Nicolini, D. 2010. Practice as the site of knowing: Insights from the field of telemedicine. ***Organization Science*****,** Articles in Advance: 1–19 – the database says 22(3): 602-620.

Olhager, J. 2003. Strategic positioning of the order penetration point. ***International Journal of Production Economics,*** 85(3): 319-329.

Olson, E. M., Walker, O. C., Ruekert, R. W., & Bonnerd, J. M. 2001. Patterns of cooperation during new product development among marketing, operations and R&D: Implications for project performance. ***Journal of Product Innovation Management***, 18(4): 258-271.

Petersen, K. J., Handfield, R. B., Ragatz, G. L. 2005. Supplier integration into new product development: Coordinating product, process and supply chain design. ***Journal of Operations Management,*** 23: 371-388.

Petersen, B.S. 2009. Airbus A380: Inside aviation's new jumbo trouble'. ***http://www.popularmechanics.com/science/space/4201627***

Pisano, G. 1996. ***The development factory.*** Boston: Harvard Business School Press.

Rothaermel, F. 2013. ***Strategic management, concepts***. New York: McGraw-Hill.

Rungtusanatham, M., Salvador, F., Forza, C., Choi, T.Y. 2003. Supply-chain linkages and operational performance: A resource-based-view perspective. ***International Journal of Operations and Production Management***, 23 (9)

Schiele, H. 2010. Early supplier integration: The dual role of purchasing in new product development. ***R&D Management***, 40(2): 138-153.

Sethi, R., Smith, D. C., & Whan Park, C. 2001. Cross-functional product development – Teams, creativity, and the innovativeness of new consumer products. ***Journal of Marketing Research***, 38: 73-85.

Simchi Levi, D., Simchi-Levi, E., & Kaminski, P. 2008. ***Designing and managing the supply chain***. New York: McGraw-Hill.

Simon, H.A., Dantzig, G.B. Hogarth, R., Plott, C.R., Raiffa, H., Schelling, T.C., Shepsle, K.A., Thaler, R., Tversky, A., Winter, S. 1987. Decision making and problem solving. ***Interfaces,*** 17(5): 11-31.

Srivastava, R. K., Shervani, T. A., & Fahey, L. 1999. Marketing, business processes, and shareholder value: An organizationally embedded view of marketing activities and the discipline of marketing. ***Journal of Marketing,*** 63: 168-179.

Szulanski, G. 1996. Exploring internal stickiness: Impediments to the transfer of best practice within the firm. ***Strategic Management Journal,*** 17: 27-43.

Tatikonda, M. V., & Stock, G. N. 2003. Product technology transfer in the upstream supply chain. ***Journal of Product Innovation Management***, 20(6): 444-467.

Thomke, S., & Von Hippel, E. 2002. Customers as innovators: A new way to create value. ***Harvard Business Review***, 80(4): 74-81.

Tsoukas, H. 2005. ***Complex knowledge. Studies in organizational epistemology***. Oxford, UK: Oxford University Press.

Ulrich, K. 1995. The role of product architecture in the manufacturing firm. ***Research Policy*** 1995 Vol.24

Ulrich, K., & Eppinger, S. D. 2011. ***Product design and development***. New York: McGraw-Hill.

Uzzi, B. 1997. Social structure and competition in inter-firm networks: The paradox of embeddedness. ***Administrative Science Quarterly***, 42.

Verona, G. 1999. A resource-based view of product development. ***Academy of Management Review***, 24(1): 132-142.

Von Hippel, E. 1986. Lead users: A source of novel product concepts. ***Management Science***, 32: 791-805.

Wheelwright, S. C., & Clark, K. B. 1992. ***Revolutionizing product development.*** New York: The free press.

Zacharia, Z. G., & Mentzer, J. T. 2007. The role of logistics in new product development. ***Journal of Business Logistics***, 28(1): 83-110.

Appendix 3.A: Interpretation of results from Table 3.6: Increasing External Site and Internal Site by one unit to raise the likelihood of product success (Standard deviations [S.D.] and means for dydic exchange intensities are shown in Appendix 3.D)

An increase of the variable *External Site* by one unit can be accomplished as follows:

(1) Increase both z-Scores for the linkage between *lead users and product design* as well as between *suppliers – tier 1 & development sourcing* by an equal amount to raise the factor score by one unit. Using the factor scores from Table 3.5 (0.730 and 0.858, respectively), the necessary increase in z-score is $x_E = 0.630$ as shown below.

$$1 = 0.730 * x_E + 0.858 * x_E$$

$$x_E = \frac{1}{(0.730+0.858)} = 0.630$$

(2) Simultaneously increase the exchange intensity for both linkages by a z-score of 0.630.

$$\text{S.D. (lead users and product design)} * x_E = 1.657 * 0.630 = 1.040$$

$$\text{S.D. (suppliers – tier 1 and development sourcing)} * x_E = 1.880 * 0.630 = 1.184$$

Using the standard deviations (S.D.) for both linkages an increase can be accomplished as follows: The linkage between *lead users and product design* needs to be raised by 1.04 levels and the exchange intensity of the linkage between *suppliers – tier 1 & development sourcing* needs to be raised by 1.18 levels towards a mode of collaboration.

An increase of the variable for the interaction effect of *internal site* and *overlap launch & ramp-up* by one unit can be accomplished as follows:

(1) Increase z-Scores for *internal site*, by raising the exchange intensity of each linkage by one level. The necessary changes in z-scores for each of the three linkage are shown below.

z-score (production planning and launch & ramp-up) =

= 1/S.D. (production planning and launch & ramp-up) = 1/1.667 = 0.600

- - -

z-score (procurement and development sourcing) =

= 1/S.D. (procurement and development sourcing) = 1/1.539 = 0.650

- - -

z-score (production and launch & ramp-up) =

= 1/S.D. (production and launch & ramp-up) = 1/1.1.700 = 0.588

The resulting increase in the z-score of internal site (1.570) can be calculated using the factor loadings from Table 3.5.

z-score (internal site) = 0.906 * 0.600 + 0.847 * 0.650 + 0.810 * 0.588 = 1.570

(2) Simultaneously increase the level of temporal *overlap launch & ramp-up* by 0.637 or 63.7%

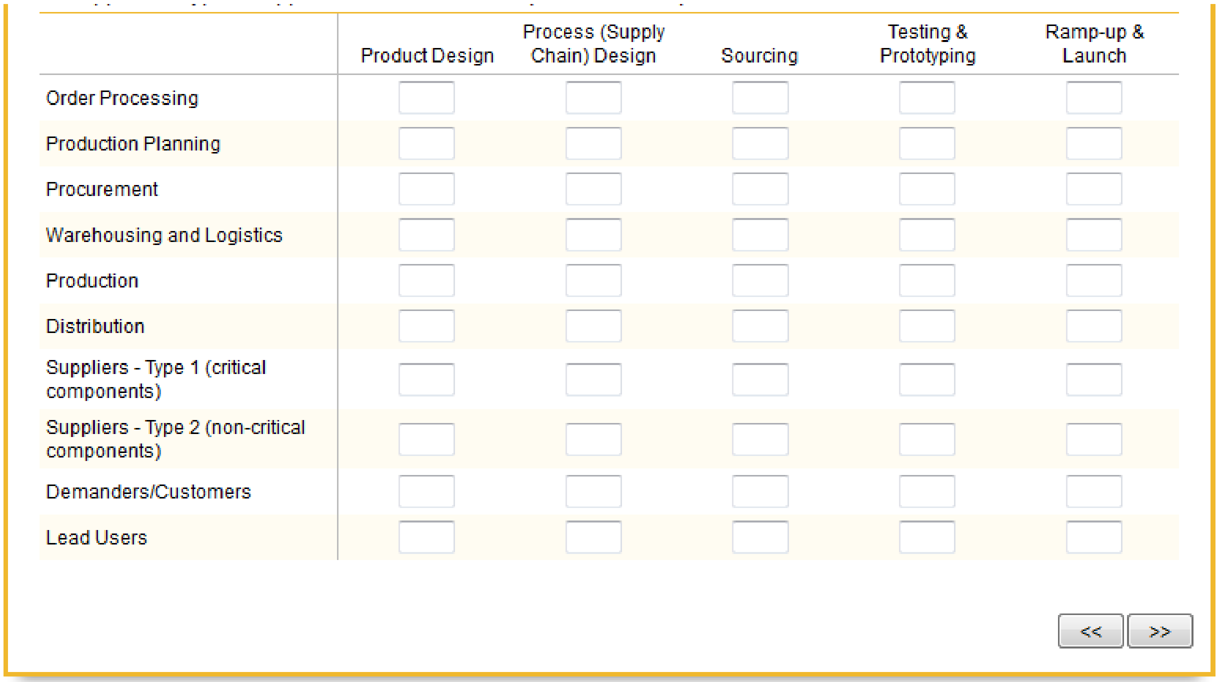
Temporal overlap launch & ramp-up = 1/1.570 = 0.637

Accordingly, in order to accomplish a final increase of the interaction effect of internal site and overlap launch & ramp-up, the temporal overlap needs to be increased by 0.637, as shown above.

Appendix 3.B: List of NAICS codes of products in the sample

Observation No.	NAICS Code	Observation No.	NAICS Code
1	334510	65	339114
2	334514	67	339113
5	339112	68	334510
7	339114	70	325211
11	339116	71	311514
12	323117	73	335911
14	339112	75	325199
15	3273320	76	333618
17	3345111	80	Confidential
18	325412	82	325211
19	334413	84	311514
20	333999	90	335911
21	333512	91	311514
22	334511	92	325199
23	311920	105	333618
24	335314	132	333618
25	339112	133	334511
28	339932	134	339932
30	333913	135	339932
32	333111		
34	311999		
36	311991		
40	332420		
41	332420		
42	334613		
44	334510		
45	339112		
49	334510		
50	339112		
51	339312		
52	339312		
54	334310		
59	339114		
60	334310		
63	339112		

Appendix 3.C: Example Matrix (10x5) for the entry of dydic exchange intensities by respondents



	Product Design	Process (Supply Chain) Design	Sourcing	Testing & Prototyping	Ramp-up & Launch
Order Processing					
Production Planning					
Procurement					
Warehousing and Logistics					
Production					
Distribution					
Suppliers - Type 1 (critical components)					
Suppliers - Type 2 (non-critical components)					
Demanders/Customers					
Lead Users					

Appendix 3.D: Means and standard deviations of exchange intensities between all 50 dyadic linkages

Descriptive Statistics

	N	Mean	Std. Deviation
OrderProcessing_ProductDesign	54	.7037	1.39581
OrderProcessing_ProcessDesign	54	1.4259	1.64376
OrderProcessing_Sourcing	54	1.2593	1.49446
OrderProcessing_Test	54	1.1667	1.72386
OrderProcessing_Launch	54	2.7963	1.74161
ProductionPlanning_ProductDesign	54	1.5185	1.43725
ProductionPlanning_ProcessDesign	54	2.4630	1.51362
ProductionPlanning_Sourcing	54	2.4630	1.48848
ProductionPlanning_Test	54	2.0370	1.69308
ProductionPlanning_Launch	54	3.2963	1.66688
Procurement_ProductDesign	54	1.9074	1.52053
Procurement_ProcessDesign	54	2.4630	1.47575
Procurement_Sourcing	54	3.5000	1.53881
Procurement_Test	54	2.0556	1.47196
Procurement_Launch	54	2.9259	1.62355
InboundLogistics_ProductDesign	54	.5370	1.04092
InboundLogistics_ProcessDesign	54	1.5741	1.67785
InboundLogistics_Sourcing	54	1.7037	1.53733
InboundLogistics_Test	54	.9815	1.29572
InboundLogistics_Launch	54	2.8148	1.74911
Production_ProductDesign	54	2.3704	1.50842
Production_ProcessDesign	54	2.8333	1.62237
Production_Sourcing	54	2.4259	1.59719
Production_Test	54	2.8148	1.68315
Production_Launch	54	3.5741	1.70019
OutboundLogistics_ProductDesign	54	.9630	1.54142
OutboundLogistics_ProcessDesign	54	1.4815	1.73467
OutboundLogistics_Sourcing	54	1.1296	1.44126
OutboundLogistics_Test	54	1.1111	1.48790
OutboundLogistics_Launch	54	2.8333	1.69071
SupplierT1_ProductDesign	54	2.8519	1.70910
SupplierT1_ProcessDesign	54	2.5370	1.64504
SupplierT1_Sourcing	54	3.1667	1.65689
SupplierT1_Test	54	2.8704	1.74881
SupplierT1_Launch	54	2.7963	1.77381
SupplierT2_ProductDesign	54	1.2407	1.37272
SupplierT2_ProcessDesign	54	1.4074	1.44742
SupplierT2_Sourcing	54	2.1481	1.54685
SupplierT2_Test	54	1.6296	1.37767
SupplierT2_Launch	54	1.7778	1.51305
Demanders_ProductDesign	54	2.3704	1.77292
Demanders_ProcessDesign	54	1.3889	1.70921
Demanders_Sourcing	54	1.0000	1.40081
Demanders_Test	54	2.0185	1.76433
Demanders_Launch	54	2.6111	1.70921
LeadUsers_ProductDesign	54	2.8889	1.88005
LeadUsers_ProcessDesign	54	1.7037	1.64408
LeadUsers_Sourcing	54	1.0556	1.40641
LeadUsers_Test	54	2.7407	1.86512
LeadUsers_Launch	54	2.7778	1.88005

Chapter 4 A product centric view on the linkage between product development and supply chains

4.1. Introduction

"Companies don't compete, supply chains compete". This statement by the CIO of Norton from 2008 indicates that many practitioners now recognize the supply chain as the central unit of competition. In the 21st century, most supply chains operate in challenging environments which are characterized by increased price sensitivity, market fragmentation into niche segments, globalization, an elevated demand for product customization, as well as higher rates of new product introduction (Christensen and Raynor, 2003; Thaler, 2003; Fixson, 2005, p.346; Searcy, 2008). Implied is that supply chains are facing more fragmented demand and more frequent new product introductions. At the same time, firms conducting new product development efforts increasingly seek to leverage competition among suppliers, as well as the expertise, economies of scale and flexibility of their suppliers (Clark and Fujimoto, 1991; Baye, 2006; Koufteros, Cheng and Lai, 2007; Simchi-Levi, Simchi-Levi and Kaminski, 2008). Therefore, competitive advantage increasingly emanates from interactions between the development of new products and their supply chains. Consequently, the intersections of *Supply Chains* (SC) and *Product Development* (PD) have become an important concern in management research (Srivastava, Shervany and Fahey, 1999; Krishnan and Ulrich, 2001; Hult and Swan, 2003; Tatikonda and Stock, 2003; Forza, Salvador and Rungtusanatham, 2005; Simchi-Levi, Simchi-Levi, Kaminski, 2008). Krishnan and Ulrich (2001), for example, examine PD literature and present several decisions about supply chain design and operation that are relevant during development.

In this chapter, and following Krishnan and Ulrich's (2001) work, we concentrate on two specific supply chain decisions and how they relate to the decision regarding a new product's architecture: the first decision is about the sourcing strategy for components of the new product and the second concerns the order fulfillment strategy for the delivery of the new product. A considerable amount of prior research has noted a strong association between supply chain decisions and products, specifically product architecture (Fisher, 1997; Novak and Eppinger, 2001; Olhager, 2003; Fixson, 2005; Simchi-Levi et al, 2008).

Product architecture is defined as "*the scheme by which the function of a product is allocated to its physical components*" (Ulrich, 1995), which gives "a comprehensive description" of what "represents the fundamental structure of the product" (Fixson, 2005). Accordingly, in this chapter we focus on how PD and the SC interact via a product's architecture. For that reason, we present our work as a *product centric view* of the linkage between PD and the SC.

Several frameworks have been proposed in prior literature and share a central hypothesis that alignment between product characteristics (such as demand uncertainty and product variety) and supply chain design benefits performance (Fisher, 1997; Simchi-Levi et al 2008; Stavrulaki and Davis, 2010). However, no prior work has investigated both conceptually and empirically the intersection and alignment between product architecture, sourcing decisions and order fulfillment strategies. To our knowledge, this is the first work to examine all three decisions in one setting. In addition, our work ties the three decisions to a shared performance indicator. The identification of shared performance indicators is a contribution in this context, and more generally, for research in the interdisciplinary space between PD and the SC (Hult and Swan, 2003). Another contribution lies in the identification of suitable dimensions that make product architecture, sourcing and order fulfillment strategies compatible for alignment. Conceptualizing product architecture, sourcing strategies, order fulfillment strategies and performance at the product-level allows us to identify such dimensions. To summarize, our central research question asks:

> *What dimensions define the alignment/misalignment between product architecture, order fulfillment and sourcing decisions at the product-level and what is an appropriate performance indicator?*

We address this question in the conceptual part of this chapter. The conceptual component of our study is structured as follows. In section 4.2, we introduce our conceptual model, which describes the principal relationships between sourcing, order fulfillment and new product development decisions that enable product success. It also summarizes the dimensions of alignment between product architecture and supply chain strategies. To that end, the conceptual model recognizes that changes in product design can facilitate the adaptation to characteristics of the supply side and the demand side of the firm. More specifically, we argue that changes in product design, in terms of simplification and component substitutability, which we refer to as *product design requirements,* need to be informed by an objective appraisal of external factors on the demand side and the supply side of the firm conducting the development effort. In section 4.3, we begin elaborating on our conceptual framework by establishing a common performance indicator and connecting supply chain performance to *product effectiveness*, one of the two main pre-cursors of financial success with new products. In addition, we discuss how the idea of *product effectiveness* can be expanded to include the concepts of *variety*, *versatility*, and *product customization* (the latter referring to the ability to configure product orders to individual customer needs). In section 4.4, we discuss how product effectiveness depends on order fulfillment and sourcing strategies and how both strategies can be enabled by properly aligning them with product design requirements. Next, in section 4.5, we adopt prior work by Ulrich (1995) and Fixson (2005), which discusses *Function-Component-Allocation* (FCA) schemes and interface characteristics, to introduce product architecture dimensions which can be used to interpret product design requirements, be connected to sourcing and order fulfillment strategies and serve to guide the work of product developers. In section 4.6 we introduce two alignment frameworks, which are based on our discussions of sections 4.4 and 4.5, and which we test empirically. To our knowledge, this study is the first to include FCA and interface characteristics combined in empirical work on the interfaces between PD and the SC.

Section 4.7 introduces our empirical work. Prior empirical studies which explore the relationship between product design and supply chains are rare (Lau, Yam and Tang, 2007). We contribute in this area, as we develop two hypotheses based on our model and test them empirically. The first hypothesis addresses the question of alignment between product architecture and order fulfillment. The second one is concerned with the alignment between product architecture and sourcing strategies. In addition, based on the notion that product architectures can also enable product upgrades (Simchi-Levi et al, 2008), we develop a third hypothesis which tests alignment between product architecture and clock-speed. Because the ability to upgrade typically benefits new products over several product generations, we use firm success rate with new products as the performance indicator in this instance.

Section 4.8 presents and discusses our results, which provide support for all three hypotheses. Specifically, the results from the tests for hypotheses #1 and #2 afford managers and researchers the ability to quantify the effect of alignment decisions on the probability of product success. Sections 4.9 and 4.10 discuss the limitations of our study, as well as its implications for research and managerial practice.

4.2. A conceptual model for alignment between external product-related factors, product design requirements, product architecture and supply chain strategies

Our overall view of alignment between NPD decisions and supply chain strategies is presented in Figure 4.1. The conceptual model in Figure 4.1 describes the relationships and alignment mechanisms and addresses how a product centric linkage between PD and supply chains will affect *product effectiveness* and by extension, *financial success* with new products. We begin elaborating on this framework in this section and continue in sections 4.3-4.6.

The purpose of alignment is to create an effective alliance of external product related factors, product architecture and supply chain strategies. Based on prior work, the core premise of our study is that decisions which create an effective alignment – between PD decisions and supply chain strategies – are made jointly by supply chain people and PD people during the product development effort (Krishnan and Ulrich, 2001; see Chapter 2). Our review in the following sections will show that each of the two decisions has the propensity to raise or lower the effectiveness of new products and that the extent to which advantages from each decision can be realized and leveraged is strongly associated with the interplay between product architecture and supply chain strategies. Therefore, we conjecture that proper alignment (strategic fit) will have a positive effect on product effectiveness and by extension on financial success with new products.

Our conceptual model recognizes that decisions about supply chain strategies need to follow an objective appraisal of external product related factors, which include market fragmentation (niches and regions), demand for configurability and price sensitivity, on the demand side, as well as supplier expertise, competition amongst suppliers, economies of scale & flexibility on the supply side. These external factors determine the appropriateness and the feasibility of supply chain strategies as well as how they need to be enabled by the product design. Important product design requirements in this context are, for example, the level to which the product can be simplified to enable supply chain processes and the degree to which components can be substituted. These product design requirements (*product simplification* and *component substitution*) clarify the important connections between product development and supply chain decisions. In the following sections we elaborate on how these abstract product design requirements of simplification and component substitutability can be and need to be translated into more concrete dimensions of product architecture to allow for effective alignment between supply chains and the product. In addition, we put specific emphasis on how changes in product architecture that increase product simplicity and component substitutability can come at the expense of *product functionality*. In our view, product functionality incorporates technical performance (e.g. processing speed of a tablet computer) as well as style, in terms of form factor or usability (e.g. thinness of a tablet computer), and thus is strongly associated with product effectiveness.

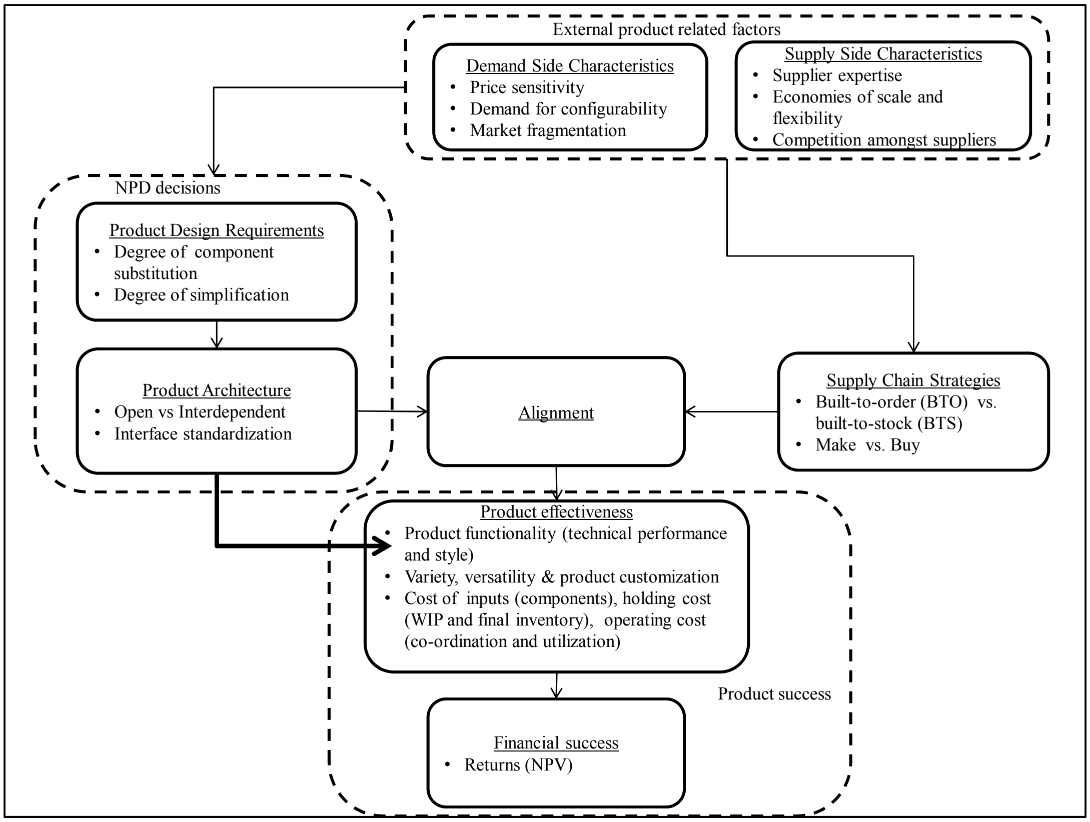


Figure 4.1 **A model of product centric linkages between product characteristic, supply chain strategies, product architecture and product effectiveness**

In the following sections, we introduce the central factors in our model, supply chain strategies, product architecture, as well as product success and their key dimensions in greater detail. We will also highlight the role of product design requirements in connecting product architecture and supply chain strategies. We begin with product success (product effectiveness and financial success) in Section 4.3 and discuss supply chain strategies in section 4.4.

4.3. Alignment, product effectiveness and product success

An important task for research in the interdisciplinary space between PD and the SC is to identify shared indicators that appropriately capture performance (Hult and Swan, 2003). For that reason, the purpose of this section is to define how the connection of PD and the SC via the product can be tied to a common performance indicator from the PD literature that is *financial success* via its pre-cursor, *product effectiveness*.

Financial success with new products has two principal pre-cursors, *PD project performance* and *product effectiveness* (Brown and Eisenhardt, 1995; Verona, 1999). PD project performance is determined by *speed* and *productivity* of the development effort. In terms of return-based measures, it accounts for the financial burden that is created pre-launch. Because supply chain activity typically begins after a new product is launched, PD project performance has little association with the alignment between product architecture and supply chain strategies.

By contrast, we argue that product effectiveness has a strong association with alignment between new product development and supply chain. In line with contemporary concepts of value creation, new products can be viewed as a bundle of attributes that includes their supply chain services, rather than the physical product by itself (Grant, 2010). For example, the bundle of a new product and its supply chain adds customer value when variety (product selection) and value-added services (orders customized to individual needs) are provided (Simchi-Levi et al, 2008). Therefore, the interplay between a new product and its supply chain raises the attractiveness of a new product and thereby the revenue streams after launch. Accordingly, product effectiveness is an important driver of post-launch cash flows and therefore an important pre-cursor of *financial success* with new products.

We view product effectiveness as a secondary construct which incorporates five product dimension: *product functionality*, *cost* (Brown and Eisenhardt, 1995; Verona, 1999) as well as *variety, versatility* and *product customization*; product functionality typically relates to technical parameters, such as processing power in computers, as well as reliability or compliance with quality standards, or style related attributes like form factor, uniqueness and appeal to buyers. *Variety, versatility* and *product customization* are not typically considered in the context of product effectiveness in the PD literature but, as we will see, they play an important role in helping define alignment.

With respect to the cost dimension, we argue that alignment between product architecture and supply chain strategies will contribute to a product's effectiveness and financial success by reducing the total cost of the delivery system. Traditionally, PD literature focusses on product cost that is associated with materials and manufacturing expenses (Wheelwright and Clark, 1992; Ulrich and Eppinger, 2011).

In this study, we take a broader view on cost and put particular emphasis on the transactional costs associated with acquiring inputs, co-ordination cost across the supply chain[10] and holding cost for inventory (Thaler, 2003; Simchi-Levi et al, 2008). In addition, prior work suggests that improved supply chain performance can optimize cash flows from new products (Srivastava et al, 1999). For example, SC performance parameters like the order fill rate and the cash-to-order (or cash-to-cash) cycle time determine when the revenue stream from new products are realized (Croxton, 2003; Simchi-Levi et al, 2008)[11]. Accordingly, we postulate that the alignment between NPD decisions and supply chain strategies is important to financial success, because it determines how efficiently the supply chain fills its orders.

In the following section, we elaborate on the concepts of variety and versatility and describe how they as well as the dimensions of cost and product functionality can improve a new product's effectiveness. Our account in this area is based on Ulrich's (1995) discussion of product change and product variety. We will also demonstrate that supply chain strategies and their interaction with the product are critical in making variety, versatility and product customization possible and feasible. Accordingly, Section 4.4 will include a discussion which shows that for product design requirements to be realized to full effect, they need to be enabled by supply chain strategy and product architecture decisions.

4.3.1. Product effectiveness through product variety and versatility

A good example for value creation through *product variety* is Swiss watch maker Swatch, who produces hundreds of different variants of the same principle type of watch. Many different faces, wristbands and hands can be combined with a base of movements and cases to create this variety. From the perspective of the firm, conducting the development effort, the possibility of more variants allows the supply chain for the new product to better satisfy very heterogeneous demands. In addition, the resulting product differentiation makes new products with more variants more attractive to a broader range of

---

[10] This includes costs for logistics, manufacturing and information systems; the difference between the best-in-class and the rest amounts to as much as 5% of the total product cost

[11] The difference in cash-to order cycle time between best in class (30 days) and median performers (100 days) can be 70 days; best in class order fill rate is approaching 100% (94%); the median ranges depending on industry 69-81%

customers and therefore creates more demand. Therefore a critical task during new product development is to define the degree of product variety that the product's architecture can enable. For example, modular products can more easily be configured to allow for many product variants.

In a similar fashion, *product versatility* can create substantial surplus value; we define product versatility as how easily a product can be changed to accommodate adaptation to varying circumstances. Product versatility thus is different from product variety as it relates to how a <u>single</u> product can be adapted to its customer's needs. For example, the adaptation to different standards of electrical power outlets creates the possibility for customers and sellers to globalize and regionalize a product. Moreover, products that are *versatile* such that they can be *re-configured* to provide different capabilities are more attractive to customers than those that cannot. A pertinent example is when different lenses can be connected to one camera model. More customer value can also be generated when the product is compatible with useful *add-on's*, such as third-party storage devices for consumer electronics, or when it can be *renewed* by simple replacements of physical elements which deteriorate with use. In the same context, product *versatility* can generate significant *annuity* through frequent replenishment of consumables, as is the case when cartridges of ink-jet printers get replaced.

However, opening the product to product variants, versatility, add-on's, renewal or replenishment of consumables has two important implications for new products and their supply chains: (1) the product needs to seamlessly morph into multiple configurations as needed and be compatible with its complementary items, and (2) customer orders increasingly consist of multiple items, rather than one, and orders can vary significantly between one customer and another. In other words, by opening the product to customer choice the demand characteristics can turn into dominantly heterogeneous, low-volume and unpredictable orders, which has serious implications for the management of the product's supply chain and in particular with the amount of inventory of each product variant to be carried. In this sense, product *variety* and *versatility* connect to both product architecture and supply chain design. We elaborate further on how supply chain designs can be critical in serving different demand characteristics and how they depend on product architecture in the next two sections.

4.4. Supply chain strategies, aligned with product design, can deliver product effectiveness

4.4.1. Order fulfillment strategies aligned with product design to deliver product effectiveness

In this section, we aim to demonstrate that choosing an appropriate *order fulfillment strategy* is critical to provide product variety and versatility, especially when products are customized. Specifically, we introduce two principal alternatives to fulfill orders: *Built-To-Stock* (BTS) and *Built-To-Order* (BTO) supply chains. The central managerial decision that creates either a BTO or a BTS supply chain, is the positioning of the *push/pull* boundary or *Order Penetration Point* (OPP) (Olhager, 2003; Simchi-Levi et al, 2008). Other literature refers to the *OPP* as the *decoupling point* (Krishnan and Ulrich, 2001; Stavrulaki and Davis, 2010). The OPP determines how far customer choice is allowed to "penetrate" into the manufacturing, assembly and delivery process. Accordingly, when offerings are delivered with a BTS supply chain, the customer has no input into the process, whilst BTO supply chains afford customers the opportunity to configure an order to their individual needs.

Which order fulfillment strategy is used has important implications for product effectiveness and in particular for product variety, versatility and cost. BTS supply chains are suitable when products are a commodity, customers are price sensitive, demand is predictable and when products are expected to be available *off-the-shelf*, as is the case with pasta, diapers or soap (Fisher, 1997; Stavrulaki and Davis, 2010). As a response to price sensitivity, process efficiency (manufacturing, assembly and delivery) is typically a priority in BTS supply chains. Despite their focus on process efficiency, it is important to note that BTS supply chains are not prohibitive to differentiation of products through variety and versatility. *Postponement* strategies present an opportunity to serve a fragmented market with BTS supply chains. In a *postponement* strategy the configuration of the final product occurs very late in the sequence of steps to make and deliver the product. Soft drinks, such as cola drinks for example, typically come in numerous permutations of packaging, whilst the key ingredient and the "application" of the product do not change. The key ingredient is compatible with numerous shapes of packaging and the final product is configured in the last step of manufacturing and assembly, the bottling plant[12]. Nevertheless, BTS supply chains do have limitations in terms of the extent to which they can enable variety and versatility and do not allow consumers to customize products.

By contrast, because of their agility (responsiveness and flexibility), BTO supply chains are suitable designs for offerings where customers have the opportunity to customize the product. BTO supply chains are suitable to meet individual demand and create value for several reasons. Firstly, it would be excessive and inefficient to make hundreds or even thousands of product permutations available off-the-shelf. Secondly, the ability to choose in itself adds to the differentiation of the offering. Thirdly, BTO strategies can be paired with information technology to allow customers to configure the final product online and thus further increase the level of customer convenience (Gunasekaran and Ngai, 2005). Baby strollers or bicycles provide good examples of markets, where combining BTO with information systems is common practice. Uppababy or Stokke, for instance, invite their customers to configure their products to their needs, order replacements and add-on parts via the internet[13].

To summarize, product variety, versatility and product customization are attractive to customers. Nonetheless, they create challenges for the operation of the supply chain. For one, they necessitate that parts or components can be substituted seamlessly, without any detrimental impact on product functionality. As we will see, product design decisions when coupled with the right order fulfillment strategy can enable the targeted level of product variety and versatility for a new product.

Product design decisions also affect the cost and speed of order fulfillment decisions. Whenever product demand is characterized by small, heterogeneous and unpredictable orders, supply chain designs need to mitigate excessive holding cost, underutilization of assets, process inefficiencies and poor customer service (Gunasekaran and Ngai, 2005; Simchi-Levy et al, 2008). Especially during the turbulent times of product launch, volatile demand can induce significant opportunity cost through unfilled orders or excessive holding cost for inventory (Calantone, Di Benedetto and Stank, 2005). An additional

---

[12] www.coca-cola.com, accessed 23JAN13; “Cola Wars Continue: Coke and Pepsi in 2010” HBS case note by Yoffie and Kim, 2011

[13] www.uppababy.com; www.stokke.com; accessed 23JAN13

operational concern in this context is responsiveness in terms of speed. Between BTO supply chains with a comparable level of choice and configurability, delivery speed can be the order winner (Olhager, 2003). To that end, prior work has emphasized a strong association between the cost and speed of supply chain operations and product design requirements. Thaler (2003) stresses the benefits of product designs that are optimized such that products will be less complex, processes can be simplified, materials/inputs will be saved and quality improves. Similarly, Fixson (2005) concludes that product designs with reduced complexity and fewer parts can be moved through the stages of manufacturing, assembly and delivery quicker and less costly than complex products with higher part counts. In other words, simplified product designs with fewer parts allow transactions and transformations to occur with greater speed and ease. Specifically, when BTO designs are complemented with appropriate product design, components can be "pulled" from prior stages (manufacturing and suppliers) as needed and thus allow supply chains to operate with close-to-zero inventory (work-in-progress and final) while maximizing responsiveness and flexibility. Presumably for those reason, many companies that increasingly compete on variety, versatility and customization, like BMW, Compaq and Dell have recently implemented BTO designs (Gunasekaran and Ngai, 2005).

We conclude that the appropriateness and the feasibility of a shift in the OPP depends on product design. In particular, our review indicates that if BTO supply chains are to maximize product effectiveness they need to be complemented with products with less complexity, fewer parts and high substitutability of components or complements that differentiate the offering. On the other hand, when component substitution can interfere with product functionality, or when processes cannot be competitive in terms of speed and cost, allowing customers to configure the order may not be the appropriate choice.

4.4.2. Sourcing strategies, aligned with product design, to deliver product effectiveness

Order fulfillment and sourcing strategies are not independent. For example, Jahnukainen and Lahti (1999) note that once BTO supply chains operations are optimized, purchased components have a 70-80% share in total cost to deliver the product to customers. This underscores the importance of sourcing strategies, which is the second critical decision that connects PD and the supply chain via the product. In this section, we will discuss how sourcing strategies for components of a new product are motivated and how they can benefit product effectiveness when they are complemented by product design. We argue that outsourcing strategies can minimize cost, enable variety and versatility, if new product complexity can be reduced and components are substitutable. Similar to our discussion of order fulfillment strategies, we also examine the impact of sourcing strategies, product simplification and component substitutability on product functionality.

Sourcing theory is traditionally informed by transaction cost economics (TCE) and concerned with the decision between producing an input within the boundaries of a firm (“make” / “insource”) or acquiring it through a market transaction (“buy” / “outsource”). Several criteria guide the decision-making process: frequency, uncertainty, the degree of transfer of technological or managerial know-how, specificity of physical (tools, machines), or knowledge related assets as well as their location and dedication. One or more of these attributes may lead to expenses, which may put the costs for one choice in excess to the alternative (Teece, 1986). The overarching goal is to minimize the total cost associated with transactions, and the choice to make or buy will be made accordingly. In the context of the intersection of PD and the SC, sourcing decisions for components of a new product can be motivated by various other objectives. Firms may *outsource* components for a new product to increase economies of scale and flexibility (Simchi-Levi, Simchi-Levi and Kaminski, 2008), or to leverage competition among suppliers (Baye, 2006) and supplier expertise (Clark and Fujimoto, 1991; Koufterous et al, 2007). Conversely, they may *insource* components to preserve the technical performance of the new product (Novak and Eppinger, 2001; Christensen and Raynor, 2003) or to prevent hold-up by suppliers (Baye, 2006) and imitation or disruption by competitors (Christensen and Raynor. 2003).

Thus, outsourcing components can raise product effectiveness in three ways. Firstly, competition among suppliers will lower the cost of components and by extension the cost of the new product. Secondly, a broader base of sources for components typically increases flexibility and therefore may allow the creation of a level of product variety and versatility that is not possible with in-house production of components. Thirdly, leveraging component supplier expertise can help to elevate the technical performance of a new product and its appeal to customers.

However, outsourcing can be undesirable when product structures are complex to the extent that they elevate co-ordination efforts for suppliers (Simchi-Levi et al, 2008). Highly complex product structures may put co-ordination costs in excess of the benefits of competition among suppliers, economies of scale and leveraging supplier expertise. Furthermore, outsourcing can be detrimental to product effectiveness, particularly when component suppliers would be required to make specialized investments. For example, if the product is highly complex such that all of its components are highly interdependent or if the interface between components and the final product is complex then suppliers may not be able to invest in the necessary resources to comply with the product's requirements. Typically, suppliers of components seek a relationship that will allow them to recover their investment and capture sufficient profits from transactions (Baye, 2006). In consequence, many potential component suppliers may be deterred if they are asked to make specialized investments. Less potential suppliers, in turn, limit the possibility of variants and versatility. By contrast, those component suppliers that commit to specialized investments may create hold-up that will elevate product cost. The third possibility is that component suppliers commit to deliver, but cannot establish a profitable relationship. In that case, they may underinvest and thus negatively affect the technical performance (product functionality) of the new product (Novak and Eppinger, 2001). Hence, we expect that it may be difficult to outsource components for highly complex and specialized new products and that the decision to insource components for a new product is strongly associated with the complexity of the product and the substitutability of components. An empirical study in the automotive industry by Novak and Eppinger (2001) confirms this notion and reports significant positive correlation between product complexity and in-sourcing.

To summarize, in order to make informed sourcing decisions, it is important to understand whether the degree of complexity and the degree of component substitutability is appropriate for outsourcing of components. This decision can be informed by an analysis of the risks of underinvestment or hold-up. If in response, the new product is simplified and component substitutability is elevated, it is critical to understand how such action changes the new product in terms of its functionality. Overall, sourcing decisions for components of new products need to be informed by an in-depth understanding of product complexity, component substitutability and functionality of the product.

In the next section, we will present concrete product architecture dimensions that appropriately capture and allow product designers to interpret the more abstract product design requirements of simplification, component substitutability, as well as product functionality. In accordance with Fixson (2005) we present how "product architecture, when properly defined and articulated, can serve as a coordination mechanism" between product (development), processes and supply chain" (p. 346).

4.5. Product design decisions and product effectiveness

The purpose of this section is to elaborate on the connections between product design requirements, product architecture and product effectiveness and to present specific dimensions of product architecture that can be related to sourcing and order fulfillment strategies. The importance of product architecture as a coordinating mechanism has been recognized by prior scholarly work in various organizational contexts, such as product development, engineering design and supply chain management (Sosa, Eppinger and Roles, 2004; Fine, Golany and Naseraldin, 2005; Vonderembse, Uppal, Hunag, Dismukes, 2006; Chiu and Okudan, 2010). For that reason, a variety of definitions and dimensions of product architecture have emerged. In Section 4.5.2 we identify specific product architecture dimensions that can guide the interaction and decision-making which connects product design, sourcing and the position of the order penetration point.

We begin by discussing the relationship between product design requirements, product architecture and product effectiveness. In the previous sections we argued that product design requirements can guide decisions about sourcing and order fulfillment strategies, if they adequately capture the degree of product simplification and substitutability of components. During the new product development process, product design requirements are translated into specific and realistic dimensions of product architecture. Therefore, the alignment or product architecture with supply chain strategies is critical to product effectiveness.

One important aspect of product effectiveness that is affected by the choice of product architecture and supply chain decisions is product functionality. Chiu and Okudan (2010), for example, note that product simplification which enables supply chain agility typically comes at the expense of product functionality. In addition, reduction of product complexity for the purpose of easier substitution of one or more parts within a sophisticated and complex arrangement will most likely have a significant impact on the technical performance of the overall system (Sosa, Eppinger and Rowles, 2004). As an example, consider highly sophisticated products, like an aircraft turbine, where there are many critical interdependencies between its many parts. Even Dell, a company typically known to allow its customers to choose the key components of their computers, limits the ability to configure its ultrathin laptops to software and peripherals[14]. Presumably, choosing a bigger hard drive, memory card or DVD drive would conflict with the constrained envelope of the product because of space and heat management. Likely because Dell needs to preserve the differentiating factor of the final product that is its ultrathin style, the company limits customer choice in this instance. Therefore, we conclude that any changes to product architecture that reduce complexity and enable component substitution in order to complement supply chain strategies can affect a product's functionality. As a consequence, changes to product architecture need to be carefully evaluated against any impact on product functionality. Thus, functionality is an important concern when choosing product architecture in the context of our framework.

We next focus on dimensions of product architecture.

4.5.1. Modular versus integral product architectures

One common way prior work has categorized product architectures is based on distinguishing between modular and integral products (Chiu and Okudan, 2010). For example, Seidel, Loch and Chahil, 2005 suggest that reduction of product complexity and enabling the interchangeability of components is strongly associated with *modularization* of product architecture. Simchi-Levi et al (2008) summarize prior work and present a framework for alignment between product and supply chains based on *modular*

---

[14] www.dell.com; accessed 23JAN13

and *integral* products. However, using a simple dichotomy of modular and integral products in a context like ours can be problematic and incomplete. The purpose of this section is to reason why this chapter goes beyond the common product architecture labels of modular versus integral and to point out the requirements for a product architecture concept/construct that better fits or purpose.

First of all, different degrees of modularity (or integrality) are difficult to articulate and measure in a generalizable way. Purely modular and integral product architectures are idealistic concepts that may not actually exist in practice. Hence, there is a need to identify how product architectures can be mapped between the extremes of modular and integral. More sophisticated models have been developed to characterize product architectures along the continuum between the extremes of modular and integral (Fine et al, 2005). Nonetheless, highly complex models may be difficult to implement universally in PD practice. Presumably for the above reasons, product and process designers' often struggle with the implementation when "something modular" is requested[15].

Secondly, another important aspect which is not clearly captured by the dichotomy of *modular* and *integral*, is the *consolidation* of functionality and components into large physical building blocks. Consolidation is an important dimension of product architecture, because it simultaneously reduces product complexity and increases the feasibility of product variety and versatility. Accordingly, the principles and advantages of the formation of building blocks or *chunks* in a PD and a supply chain context have been discussed by Ulrich and Eppinger (2011). The idea of product consolidation also receives increasing attention by practitioners. For example, the former Airbus manager and current leader of Sietas Shipyards states in the Financial Times Germany (January 3, 2011) that "at Sietas, it is paramount that the end-product gets assembled as late as even possible, from less components, which ought to be as large as they can be". He adds that the objective to reduce the number of components through clustering is a key to achieve product success. The example illustrates that a manufacturing and assembly strategy that successively reduces complexity may be advantageous especially for products of

---

[15] This insight stems from the author's 15 years of work as a practitioner in product development and process development of complex systems in the Biopharmaceutical Industry, particularly from many informal conversations with product designers

considerable size and number of parts, such as aircraft, ships, and large size vehicles (truck, trains). In this context, Olhager and Wikner (1998) introduce the concept of *material profiles*. Products like aircraft or ships would be classified as "A" type[16], because the number of parts is greatly reduced as the product nears the assembly stage and further as it reaches the end customer. Implied is that product consolidation serves as a mechanism to simplify manufacturing and assembly process, as well as maintenance, repair and quality control.

For similar reasons, consolidation can be advantageous for products with a high degree of variety and versatility. Consolidated architectures can be leveraged in built to order (BTO) strategies such that products get converted into their final configuration from a limited number of building blocks, as is the case with personal computers, bicycles or baby strollers. In Olhager and Wikner's (1998) terminology, comparable products are said to have "X" type *materials profiles*.

Finally, a concept that is purely based on modularity does not adequately capture how structuring the product architecture in a way that compliments sourcing and order fulfillment strategies will affect the functionality of the product. For that reason, we will place particular emphasis on the impact of product architecture decisions on product functionality in the next section.

4.5.2. A more complex view of product architecture based on Function Component Allocation

Scholars like Fixson (2005) and Ulrich (1995) have advanced the viewpoint on product architecture and its impact on supply chains considerably beyond assigning broad surface level labels for the entire product, like modular and integral. Both authors suggest that product architecture can be assessed jointly via two important concepts: *Function-Component-Allocation* (FCA) and *Interface Characteristics*. We will focus on discussing FCA in this section and we will return to the concept of interface characteristics in Section 3.5.2. Ulrich and Fixson created a framework in which product architectures can be mapped between the extremes of modular and integral and, as a consequence,

---

[16] In Olhager and Wilkners' (1998) designation, the top of the letter represents the number of distinct items at the end customer, relative to the number of distinct items at the assembly stage in the middle of the letter, relative to the number of distinct items in the early stages of manufacturing at the base of the letter

promises a more fine-grained understanding of the relationship between product architecture and supply chain designs. We adopt the FCA scheme shown in Figure 4.2 for our empirical research because it captures important product architecture dimensions like consolidation, the possibility to substitute components, as well as product functionality within a single framework.

In accordance with Ulrich (1995) and Fixson (2005), FCA is defined as a characteristic feature of the product architecture that describes how functions are dominantly allocated to components. *FCA maps* afford four categories of product architectures depending on the number of components that provide certain product functionalities. Product architectures in which few components provide a lot of functionality are called "*Integral-consolidated*". "*Modular-like*" architectures exhibit a near 1:1 component to functionality mapping. "*Integral-fragmented*" product architectures imply that many parts and components participate to provide a few key functionalities of the product. Finally, "*Integral-complex*" product architectures imply that a holistic block of many interdependent parts defines a product's functionality.

Product architectures can, of course, be assessed at different levels of abstraction. Different levels of abstraction lead to different results even within one and the same product. Consider for instance, the difference between a personal computer (PC) and one of its key components the processor. In an FCA scheme, a PC would be characterized as modular-like, whilst its processor would be classified as integral-complex. It is therefore important to be clear about the level of abstraction of product architecture dimensions. In this study, we examine product architecture dimensions at the product level, as we do with supply chain strategies.

From a practitioner's perspective, real products can be better allocated to one of the four architecture types than to a (much more vague) dichotomy of modular and integral. Similarly, the four architecture types provide more specific tool for the interpretation of product design requirements by product developers. As a consequence, we are using the full framework presented in Figure 4.2 to measure product architecture in our empirical research.

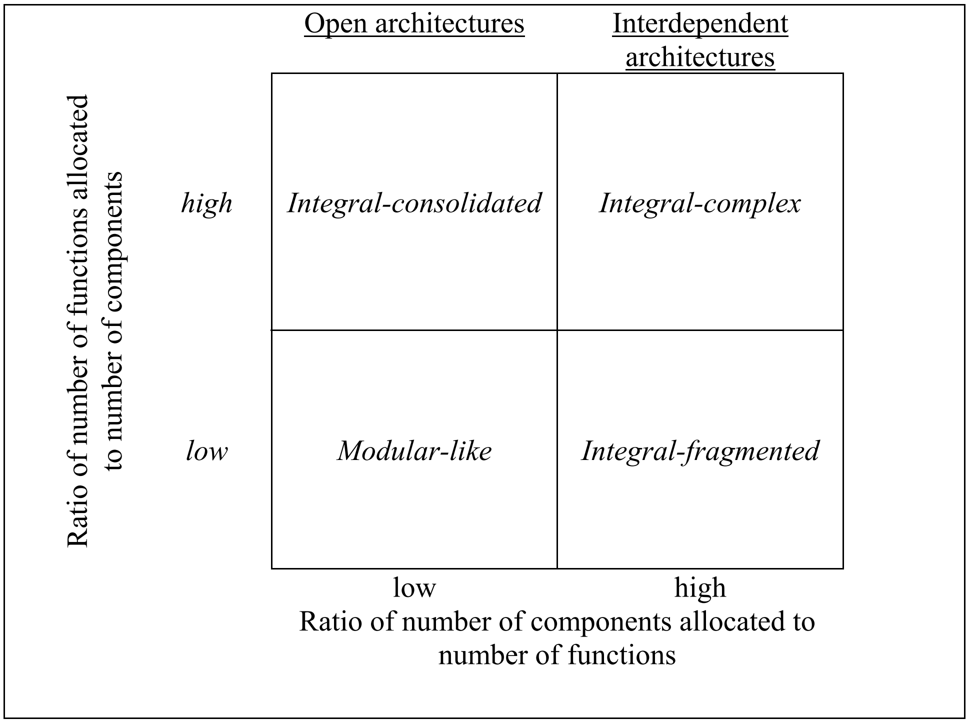


Figure 4.2 Function-component-allocation (FCA) scheme for new products. Adopted from Fixson (2005)

Specifically for the purpose of alignment between product architecture and order fulfillment strategies, we propose to group the four architecture types into *open* and *interdependent* architectures. As shown in Figure 4.2, the ratio of the number of components allocated to product functions decreases from right to left. Accordingly, a shift towards *Integral-consolidated* and *Modular-like* products represents a simplification of the product architecture. Further, because product functionality can be traced to components or building blocks, it is clear how substitution of components will affect the product's overall functionality). For that reason, we consider *Integral-consolidated* and *Modular-like* products to be simplified and *open* for substitution of components. Hence, we group them under *open architectures*. By contrast, for *Integral-complex* and *Integral-fragmented* architectures, the impact of component substitution on overall functionality is not clearly identifiable. Because of the interdependence between components and functionality, we group *Integral-complex* and *Integral-fragmented* architectures under *interdependent architectures*. In the specific context of order fulfillment strategies, simplification and consolidation are the most critical product characteristics. Based on our discussion so far, both are more appropriately captured and more precisely defined by the dichotomy of *open/interdependent* than by the surface labels of *modular* and *integral*.

4.6. Alignment frameworks for product architecture

In general terms, strategic alignment has been recognized as an important issue in operations and supply chain management. Alignment is an important issue when capabilities or priorities in different areas of the business are not independent. The basic theoretical argument is that those firms that create a fit (accomplish alignment) between the interdependent capabilities or objectives of different areas within an organization exhibit better performance than those that do not. Misalignment (or a gap) would take the form of a difference between priorities or capabilities in one area (e.g. corporate-level strategy) and the emphasis placed on the same issue in a dependent area (e.g., functional-level strategy) (Vachon, Halley and Beaulieu, 2009). One prominent example of an alignment framework is Hayes and Wheelwright's *product-process-matrix*, which posits that process choice (e.g., a job shop versus a continuous flow production process) should complement the competitive priorities of the firm (e.g., flexibility versus efficiency) (see Safizadeh, Ritzman, Sharma and Wood, 1996). Fisher's (1997) *product-supply chain matrix* similarly suggests that efficient processes in a supply chain should be aligned with low profit margin, low variety products, while responsive processes should be aligned with high profit margin, high variety products. Vachon et al (2009) discuss alignment between competitive priorities of customers and suppliers and Narasimhan, Kim and Tan (2004) suggest that alignment between corporate level and functional level SCM strategies leads to higher levels of performance, in terms of financial performance, customer satisfaction and market performance. In this section, we develop frameworks and hypotheses about the alignment between product architecture, sourcing strategies, order fulfillment strategies and clock-speed, and we conjecture about the impact on performance.

4.6.1. Product architecture and order fulfillment strategies

Our first framework and hypothesis concerns the alignment between product architecture and order fulfillment strategies, which we refer to as *downstream alignment*. We refer to this concept as downstream alignment, because the choices of *OPP* and product architecture determine how the demand side or the downstream side of the supply chain interacts with customers. As shown in Figure 4.3, our alignment framework collapses the four product architecture types into two categories as shown in Figure 4.1, namely open and interdependent architectures. It also includes the two salient downstream strategies that are built-to-order (BTO) and built-to-stock (BTS). We collapse the four product architecture types, because the main dimensions of product architecture in this context are simplification of product structure to simplify supply chain processes, substitutability of components and the impact of interdependencies on functionality of the product. As we note in Section 4.4, these dimensions can be expressed sufficiently through open and interdependent architectures. We conjecture that alignment between product architecture and downstream strategies is created when open architectures are matched with BTO supply chains or when interdependent architectures are matched with BTS supply chains. BTO supply chains need to respond to individual customer needs and therefore require a high degree of substitutability of components. Open product architectures allow for component substitution without an impact on the overall functionality of the product. Moreover, open product architectures represent simplified product structures which benefit the co-ordination of the assembly processes. By contrast a combination of an open architecture with a BTS supply chain represents a mismatch, because it represents at least one of two missed opportunities to create customer value: (1) When external product related factors advocate a BTS supply chain, because the product is expected off-the-shelf, there is no benefit from an open product architecture and hence there is a missed opportunity to optimize product functionality. (2) When the product architecture allows substitution of components without impact on the overall functionality and the product is not expected *off-the-shelf*, a BTS supply chain represents a missed opportunity to configure the product to individual customer needs and to minimize holding cost for final product inventory.

Another mismatch is created when an interdependent architecture is paired with a BTO supply chain. Firstly, the interdependence between components means that configuring the product to individual customer needs will impact on functionality. Secondly, the co-ordination of the assembly process will be costly and slow. Therefore, interdependent product architectures should be matched with BTS supply chains.

	Built-to-order (BTO)	Built-to-stock (BTS)
Open Product Architecture	*match*	*mismatch*
Interdependent Product Architecture	*mismatch*	*match*

Figure 4.3 Alignment (match) between product architecture and supply chain design

In sum, alignment between downstream strategies and product architecture (downstream alignment) can be created with matches as shown in Figure 4.3. We hypothesize that downstream alignment will have a positive impact on success with new products.

Hypothesis #1: The relationship between downstream alignment and product success will be significant and positive.

4.6.2. Product architecture and sourcing strategies

The topic of sourcing strategies leads to our second framework and hypothesis, which is concerned with alignment between product architecture and sourcing,which we refer to as *upstream alignment*. We refer to this concept as upstream alignment, because the choices of *sourcing* and product architecture determine how the demand side or the upstream side of the supply chain interacts with suppliers. Our discussion earlier has shown that the primary goals in sourcing of components are to minimize the total cost associated with transactions and to leverage the expertise of suppliers, where possible and feasible. What is possible and feasible depends on co-ordination cost, the existence of alternative component suppliers and the impact on overall functionality of the product. When product architectures allow for many alternative components and the substitution does not impact on functionality of the product, outsourcing (buy) components is an appropriate decision. In that scenario, product *cost* can be optimized through competition amongst suppliers of the component without incurring any hold-up or excessive co-ordination costs. Product architectures that enable outsourcing of components in that manner are *open*, because the functions of components or building blocks are clearly defined. Suppliers can focus on optimizing functionality of their component and thus a clearer co-ordination of their work is possible. Again, we expect that the appropriate strategy here is to outsource (buy) components or building blocks.

By contrast, *integral-complex* products are more prohibitive to an outsourcing strategy, because of the interdependence between the components. For one, the impact of component substitution on overall product functionality is not clear and therefore functionality may be negatively impacted. Furthermore, in order to improve the product's functionality, multiple components need to be optimized together. As a consequence, a clear co-ordination of the work between suppliers can easily require more effort than in-house production. Therefore, the appropriate strategy for components of *integral-complex* products is to in-source (make).

In accordance with Ulrich (1995) product architecture can be assessed in a product development context at the product-level, jointly through FCA and interface characteristics. Interface characteristics include coupling and standardization. According to Ulrich (1995), at the product-level the coupling of interfaces is typically implicit in the designation of product architecture through FCA, such that integral product architectures exhibit coupled interfaces, whilst modular product architectures typically exhibit de-coupled interfaces. Fixson (2005) has proposed a method to operationalize interface coupling through interface *reversibility* and interface *intensity*. At the product-level, interface *reversibility* expresses the efforts necessary to unmake the product. Interface *reversibility* is important, because higher reversibility can facilitate better quality control and higher product versatility. Interface *intensity*, at the product-level, expresses the level of energy-, spatial- and information-type interactions within the product. Interface *intensity* is important as an indicator of the interdependence within the product's constituents. Following Ulrich (1995), we expect that at the product-level *integral-complex*, *integral-fragmented* and *integral consolidated* all exhibit significantly different and lower interface reversibility and higher interface intensity than *modular-like* products. We will not test this claim with a formal hypothesis, since it has been established before. However, we will present results on interface characteristics for the four FCA types to strengthen the validity of our empirical lens, which views interface reversibility and intensity to be implicit in the FCA-type when they are assessed at the product-level.

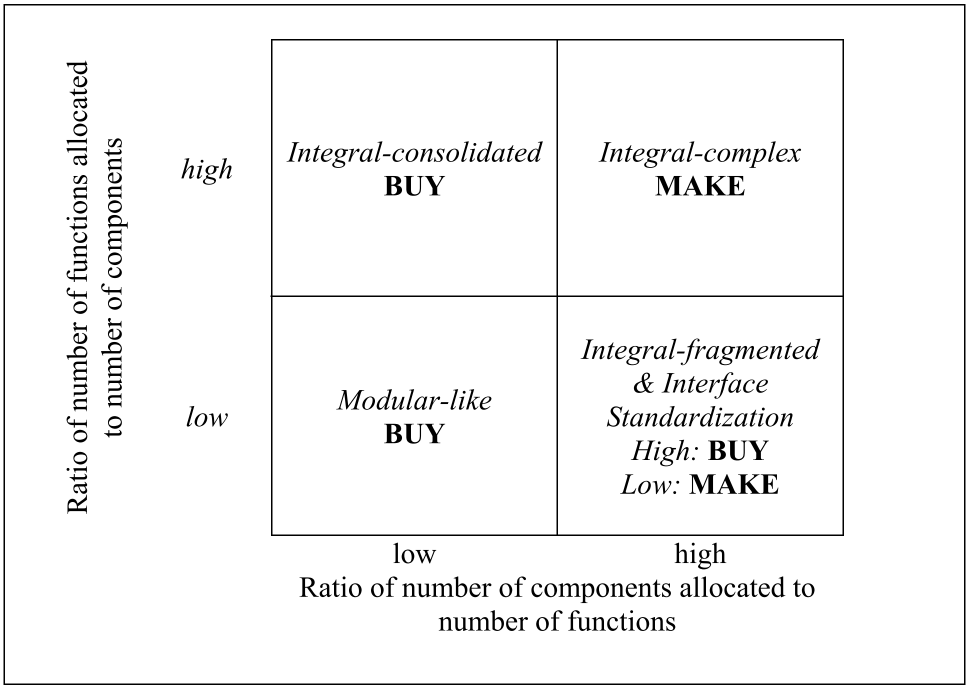
Another important interface characteristic of a product is the degree of standardization. Unlike, interface *reversibility* and *intensity*, we expect interface standardization to be independent of FCA-types.

Interface standardization is a property of the components more so than it is of the overall product architecture. In other words, highly coupled architectures can be accomplished using components with standardized interfaces, whilst modular-like architectures can be realized with non-standardized interfaces. Nonetheless, interface standardization can be an enabler for *sourcing strategies*, because it determines the availability of alternative components and enables component commonalities across different product lines (Christensen and Raynor, 2003; Fixson, 2005). On the other hand, interface standardization is less critical to order fulfillment strategies, because variety and versatility can be accomplished with non-standardized, proprietary interfaces. Dyson, for example, offers a base model vacuum cleaner (DC-series) that can be customized in 9 categories of product attributes along with different color schemes based on highly proprietary component technology and interfaces [17]. In fact, proprietary interfaces can be an effective mechanism to protect companies from potential rivals when overall product functionality is critical and component technologies themselves are not proprietary (Christensen and Raynor, 2003).

For similar reasons as with *integral-complex* products, the appropriate strategy for components of *integral-fragmented* products is to in-source (make). This is true, in particular when the interface standardization is low and not many alternatives may exist. On the other hand, when the degree of interface standardization of *integral-fragmented* products is high, the focal organization takes on the primary role of an integrator. Integrators typically focus their expertise on the functionality of the product as a whole rather than on optimizing a broad array of components. To that end, if interfaces are standardized and many alternatives to outsource exist, it may be more effective to leverage suppliers' expertise to optimize components. Therefore the appropriate decision for *integral-fragmented* products is to outsource (buy) when interfaces are standardized to a high degree and to insource (make) when interfaces are not standardized. An alignment framework is shown in Figure 4.4.

---

[17] Categories include uprights, canisters, handheld/cordless, designed for homes with pets, lightweight, suitable for every floor type, certified asthma & allergy friendly, easy to maneuver, easy to store; www.dyson.com, accessed 23JAN13



Ratio of number of functions allocated to number of components	low Ratio of number of components allocated to number of functions	high Ratio of number of components allocated to number of functions
high	*Integral-consolidated* **BUY**	*Integral-complex* **MAKE**
low	*Modular-like* **BUY**	*Integral-fragmented & Interface Standardization* *High:* **BUY** *Low:* **MAKE**

Figure 4.4 **Alignment (match) between product architecture and sourcing strategies**

In sum, alignment between sourcing strategies and product architecture (upstream alignment) can be created as shown in Figure 4.4. We conjecture that upstream alignment will have a positive impact on success with new products.

Hypothesis #2: The relationship between upstream alignment and product success will be significant and positive.

4.6.3. Product architecture and clock-speed

Increasing rates of new product introduction have become an important factor of competition in most industries (Fixson, 2005; Simchi-Levi et al, 2008). In consequence, many companies need to cope with and facilitate frequent upgrades to their products. Following Ulrich (1995) and Simchi-Levi et al (2008) we conjecture that there is a strong association between product architecture and successful product upgrades. In particular, the notion of ease of component substitution through product simplification affords an alignment framework for clock-speed which is very closely related to the one in section 3.5.1, albeit with a different time horizon and level of observation. Specifically, we expect that open architectures are appropriate when the clock-speed is high. Conversely, we expect that interdependent architectures are appropriate when clock-speed is low (Figure 4.5). What is different with an alignment framework between product architecture and clock-speed is the performance indicator. Product success, as introduced in the previous context is not suitable, because successful product upgrades express themselves long term, across several product generations. In particular, the ability to quickly upgrade a product should benefit time-to-market and lead to greater productivity in PD projects across a span of several product generations. As a consequence, we select firm success rate with new products as a performance indicator.

	High clock-speed	Low clock-speed
Open Product Architecture	*match*	*mismatch*
Interdependent Product Architecture	*mismatch*	*match*

Figure 4.5 Alignment (match) between product architecture and clock-speed

Hypothesis #3: The relationship between clock-speed alignment and firm-level development success rate will be significant and positive.

4.7. Methods

4.7.1. Data sources and data collection

A survey design was used to collect the data for this research. The final survey design was based on a careful review of prior empirical literature in this area, informal exchanges with experienced practitioners in the area of new product introduction and a pilot test of an initial survey which included a group of ten product managers.

Each observation corresponds to one newly launched product. In our invitation to the survey, we asked the participants to report on products that were launched within the last 5 years (2007-2012). We also informed potential respondents that we are looking for a balance between unsuccessful and successful new products, and thereby encouraged them not to select only their best PD projects.

We contacted and recruited participants from our personal professional networks, through the membership of a large U.S - based supply chain management association and through professional networking services (PNS). We primarily contacted individuals whose professional profile indicated that they had recently been involved in either new product development or new product introduction and who had responsibilities that related to the supply chain for new products. A total of 3,130 individuals were contacted as lead respondents, primarily via email and phone, out of which approximately 300 indicated an initial interest in participating. Out of this group, 141 surveys were returned via an online data collection platform. Most non-respondents indicated that they were prohibited from participating either because of insufficient data and records about their PD projects or because of lack of time and resources. 89 surveys were not considered, because they did not return one or more of the key variables of this study, which left a final sample of 52 responses that were included in or analysis. After an initial review of our survey items, most respondents indicated that because of the cross-functional nature and depth of our questions, they had to first collect the project data by accessing project records or holding meetings with project team members. The fact that most, if not all responses, are based on the company's project records or on input from multiple project team members should have contributed to mitigate the problematic effects of single methods, or single-response bias in empirical PD research (Ernst, 2002).

4.7.2. Measurement and variables

In the PD literature, it is common to assess a new product's success through its overall *financial performance* (Brown and Eisenhardt, 1995; Ernst, 2002). Financially successful new products generate greater cumulative cash inflows than cumulative cash outflows over a defined period of time and make them profitable (Wheelwright and Clark, 1992; Ulrich and Eppinger, 2011). Initially, the profitability has been assessed in "return maps", which represented graphically cumulative sales revenue, investment and development cost, the resulting profits and the point of break-even (Wheelwright and Clark, 1992). More recently, the net present value (NPV) of a development project has been accepted as an aggregate measure to assess product success because it captures timing, expenses and revenues from a new product in one indicator (Kerzner, 2001; Ulrich and Eppinger, 2011)[18]. In our empirical work, product success was measured as a dichotomous variable, based on a comparison of expected and actual returns (NPV) from new products. Accordingly, the respondents were asked to report whether the product met or exceeded expectations from the time of launch at a post-launch review. As a consequence, we suppressed the effects of overly optimistic estimates for product success (NPV) prior to launch.

Upstream alignment was also measured as a dichotomous variable. For each product the sourcing strategy for components was classified as *make* or *buy* by the respondents. In addition, the respondents classified the product architecture based on frameworks proposed by Ulrich (1995) and Fixson (2005). Alignment was determined in accordance with Figure 4.3.

The variable for *downstream alignment* was also dichotomous. For each product the supply chain was classified as a *BTO* or a *BTS* supply chain by the respondents, based on descriptions by Olhager (2003) and Simchi-Levy et al (2008). In addition, the respondents classified the product architecture as an interdependent or an open architecture based on frameworks proposed by Ulrich (1995) and Fixson (2005). Alignment was determined in accordance with Figure 4.4.

In accordance with prior work (Pimmler and Eppinger, 1994; Fixson, 2005) interface standardization, reversibility and intensity were assessed as a product-level attribute by respondents on a 5-point Likert-scale, where 5 and 4 represented a high degree of each interface characteristic and 1 and 2 represented a low degree of each interface characteristic.

The industry clock-speed for each product was determined by a secondary researcher in accordance with Fine's (1998) designation based on NAICS codes for each product. In order to establish additional, external validity for our clock-speed designation, we computed measures of sales variation, following Mendelson and Pillai (1999). Clock-speed alignment was determined in accordance with Figure 4.5. Firm success rates for new products were returned as percentages by our respondents.

---

[18] The 2nd Edition of the Handbook of the product development management association (PDMA; Kahn, 2005) presents the net present value (NPV) as a "method to evaluate comparable investments in very dissimilar projects".

As suggested in prior models of product success (Brown and Eisenhardt, 1995), we controlled for the exogenous factor of changing market conditions in the assessed period through a measure of munificence (MUNI) (Edelmann and Yli-Renko, 2008). Based on prior work by Dean (1995), Dess and Beard (1984) and Bamford, Dean and McDougall (2000), changes in munificence will be calculated for a five year period around the launch of the new product. The change in munificence for the product in question will be calculated based on industry shipments (extracted from the annual survey of manufacturers: ASM).

4.7.3. Sample demographics and PD project data

The sample includes 52 PD projects from a wide range of industries. Among them are development projects for new toys, consumer electronics, medical devices, automotive products, micro-electronics and industrial machinery (A list of NAICS codes of all products is shown in appendix A).

The mean success rate of participating firms with all of their new products was 68.1% (N=39, Std. Dev. = 24.05), which is in line with previously reported figures (Crawford and Di Benedetto, 2008) and therefore indicates representativeness of the sample. Some of the firms did not report typical success rates with their PD projects because of concerns with confidentiality.

The fraction of successful PD projects within our sample was 53.8%. The majority of the new products in the sample were launched after 2010 (51.9%), and 96.2% were launched after 2007, which satisfied our requirement for a launch time within the past five years.

4.8. Analyses, Results and Discussion

4.8.1. Changes in sourcing strategy before and after launch

As an important descriptive observation, we report the fraction of projects where the sourcing strategy was maintained before and after launch. For 63 percent of the products in our sample the sourcing approach chosen during development was maintained after launch. Accordingly, based on this sample, we can conclude with 95% confidence that in at least 50% of PD projects the sourcing approach chosen during development is maintained after launch.

4.8.2. Product Architecture and Interface Characteristics

As another important descriptive observation, we report interface characteristics, specifically reversibility and intensity, for the four FCA-types. In order to verify whether interface characteristics are implicit in function-component-allocation (FCA), we compared the standardized (Z-scores) values for interface reversibility and intensity for the independent groups of products that were developed with a *modular-like* architecture with the three groups that were developed with *integral-consolidated*, *integral-fragmented* and *integral-complex* architectures respectively. We conducted this analysis not to formally test a hypothesis, but to establish external validity for the distinction between *modular-like* and *integral* architecture types in the framework. As noted above, this distinction is important in our context, because of our claim that integral architectures with coupled interfaces can be suitable for built-to-order supply chains once they are consolidated.

	Mean (Modular-like)	Mean (Integral-consolidated)	Mean (Integral-fragmented)	Mean (Integral-complex)	F-statistic	SIG.
Interface Reversibility	0.472	-0.236	-0.360	-0.380	2.964	0.041*
Interface Intensity	-0.681	0.284	0.426	0.681	8.179	0.000*

(1) Levene's test confirmed equality of error variances for Interface Reversibility (0.060)

(2) Pairwise comparison showed that the difference between the Interface Reversibility for the group with Modular-like Function Component Allocation (FCA) is significant ($p<0.05$)

(3) Levene's test confirmed equality of error variances for Interface Intensity (0.315)

(4) Pairwise comparison showed that the difference between the Interface Intensity for the group with Modular-like Function Component Allocation (FCA) is significant ($p<0.05$)

Table 4.1 Results from analysis of variance (ANOVA) of interface characteristics for four FCA types

Table 4.1 confirms that within our sample, the averages for interface characteristics of the three FCA types with the designation *integral* are different from and higher than modular-like products. In addition, there is no difference in interface reversibility and intensity between the three FCA types with the designation *integral.* Consequently, the distinction between *modular-like* products and the three integral architecture types in the FCA scheme from Figure 4.2 implicitly includes interface *reversibility* and interface *intensity*, as we expected.

4.8.3. Upstream alignment, downstream alignment and product success

We tested hypothesis 1 and 2 simultaneously in a binary logistic regression model. Accordingly, our model has two categorical independent variables that represent alignment (or misalignment) in accordance with Figures 4.3 and 4.4 – one for *downstream alignment* and another for *upstream alignment*. As discussed earlier, we include environmental munificence (MUNI) as an important exogenous variable. Thus, our model for the test of hypothesis 1 and 2 is as follows:

$$\textit{Product Success}^* = \beta_0 + \beta_1 \, x \, (\textit{Downstream Alignment}) + \beta_2 \, x \, (\textit{Upstream Alignment}) + \beta_3 \, x \, (\textit{MUNI})$$

with Success*= ln (Success/(1-Success)) and Success representing the probability that the NPV target was met or exceeded in the post-launch review. The impact of each variable is expressed through β_i. Its value translates one unit increase of the variable in percent change in odds to meet or exceed the NPV target as $e^{\beta i} - 1$.

The results, shown in Table 4.2 indicate that based on the Chi-square statistic of the reduction in Log-Likelihood, the Nagelkerke Pseudo R-square, sensitivity and specificity the model the fit is appropriate. Furthermore, the parameter estimates confirm that the impact of *downstream alignment* and *upstream alignment* on product success was significant and positive. Thus, hypotheses #1 and #2 are supported. The effect of MUNI was not significant in our sample.

	Parameter Estimate	SIG.
Intercept	0.256	0.462
Downstream Alignment	1.187	0.002**
Upstream Alignment	0.797	0.036*
MUNI	-7.721	0.151
Notes: *Significant at p<0.05 ** Significant at p<0.01 Model Tests: ChiSquare (-2LL) = 19.148; SIG <0.05 (0.0003); Nagelkerke Pseudo RSquare = 0.412; Specificity = 79.2%; Sensitivity = 78.6%		

Table 4.2 Results of binary logistic regression of downstream alignment, upstream alignment and munificence on product success

It is important to note that our primary goal was to assess significance and magnitude of the coefficients for *downstream alignment* and *upstream alignment* more so than to explain variance in the sample. Based on that premise and the results shown in Table 4.2, we conclude that our model has reasonable utility. The parameter estimates in Table 4.2 can be interpreted such that accomplishment of *downstream alignment* will raise the probability of product success by 69 percent, and the accomplishment of upstream alignment will raise the probability of product success by 55 percent.

4.8.4. Clock-speed alignment and firm success

We tested hypothesis 3 by comparing the firm success rates for the independent groups of products that accomplished clock-speed alignment and those that did not.

	<u>Mean</u> FCA & Clock-speed - Aligned	<u>Mean</u> FCA & Clock-speed – Not Aligned	F-statistic	SIG.
Firm success rate [%]	74.3	59.1	4.125	0.049*

*: Result is significant at $p < 0.05$

Table 4.3 Results from analysis of variance (ANOVA) of firm success rates between PD projects with and without clock-speed alignment

Table 4.3 shows the results from a t-test, which illustrates that the firm success rate with new products is higher for the group of products where clock-speed was aligned with product architecture (74.3%) and significantly different from the group of products where clock-speed was not aligned with product architecture (59.1%).Thus, we conclude that hypothesis 3 is supported.

4.9. Limitations

The broad range of industries represented in this study (reference Appendix B) suggests that the results are generalizable across many product development contexts. One possible limitation is that because the data is collected with a survey design, there is a risk of subjective and single-response bias (Ernst, 2002). Based on conversations with our participants during the data collection period, we expect that this effect has been mitigated to a large extent by the depth and complexity of our survey design. We learned that many, if not all of them, had to consult project records and multiple team members before they were ready to submit their responses. Finally, we expect that we have added sufficient rigidity to definition of product success by asking respondents to report whether the financial forecasts from the time of launch have been met or exceeded at the post-launch review. First of all, financial planning for new products that includes generation of forecasts at time of launch and a comparison with actuals during a post-launch review is standard practice in larger firms. Secondly, the products in our sample have already been introduced to the marketplace and, thus, there is no incentive to justify project continuation or resource allocation with overly optimistic financial forecasts. Based on that premise, accurate records should be available and respondents have little to gain from reporting their perception rather than facts.

4.10. Implications for Management and Research

In this study, we have presented a product-centric view of the relationship and interdependency between product development (PD) and the supply chain domain. Specifically, we assessed the impact of three important product development decisions that pertain to the alignment between product architecture, supply chain strategies and clock-speed. For alignment between product and supply chain, we have focused on sourcing strategies and order fulfillment strategies. Sourcing strategies are characterized by a make or buy decision for components, whilst order fulfillment strategies are characterized by a decision about the order penetration point which, in our context, creates a dichotomy of built-to-order (BTO) and built-to-stock (BTS) supply chains. We adopted prior ideas to conceptualize product architecture dimensions at the product-level, based on function-component-allocation, implicit interface coupling (intensity and reversibility), as well as interface standardization (Ulrich, 1995; Fixson, 2005).

In the conceptual part of our chapter, we have developed a theoretical model which connects upstream alignment and downstream alignment with a common performance indicator that is *product effectiveness*. Because the quest for common performance indicators is critical to research in the interdisciplinary space between PD and supply chain management (SCM), and because we integrate product architecture, sourcing and order fulfillment strategies in one framework, we view our model as a major contribution of this chapter. In the empirical part, we report that *upstream alignment* and *downstream alignment* have a significant and positive impact on success with new products, the main consequent of product effectiveness. The results of our binary logistic regression allow us to quantify how managers can increase the likelihood of product success by aligning product architecture with their decisions about supply chain strategies. One particular area where our findings can benefit managerial decision-making is when firms are contemplating a switch from BTS to BTO supply chains and they need to evaluate the balance of benefits, costs for re-design and trade-off's in product functionality.

We see another important contribution in our work in confirming that alignment decisions are complex problems which require a broad managerial horizon. Specifically, our review has shown that *upstream alignment* and *downstream alignment* concerns many areas in the domains of product development (PD) and supply chain management (SCM). In the supply chain domain, alignment (or misalignment) can affect order processing (via the internet), production planning, procurement of components, production (manufacturing and assembly) and logistics (inbound and outbound) alike. Likewise, in the PD domain, alignment affects product and process design, sourcing, testing and launch activities.

Last, we report that the firm success rate with new products is different and higher for firms that generated alignment between product architecture and clock-speed than for those that did not. This result is based on a somewhat simplified perspective, as there are many possible contributors to firm success rates with new products (Ernst, 2002). Nonetheless, the result encourages further work in this area. One way to verify our results would be to compare products across several generations of upgrades.

In general, we hope that this study provides an appropriate platform for more empirical tests with the same methodological basis. Future research in this area could examine alignment and misalignment across a more detailed spectrum of BTO supply chains and FCA types. Specifically, a more fine-grained alignment framework between built-to-stock, made-to-order, assemble-to-order, design-to-order supply chains and all four FCA could be proposed and tested. However, it needs to be cautioned that the inclusion of more variables will most likely necessitate substantial sample sizes to obtain sufficient and representative distribution across the spectrum of FCA types and BTO supply chains.

References

Bamford, C. E., Dean, T. J., & McDougall, P. P. 2000. An examination of the impact of initial founding conditions and decisions upon the performance of new bank start-ups. ***Journal of Business Venturing***, 15(3): 253-277.

Baye, M.R. 2006. ***Managerial economics and business strategy***. New York: McGraw-Hill.

Brown, S. L., & Eisenhardt, K. M. 1995. Product development: past research, present findings, and future directions. ***Academy of Management Review***, 20(2): 343-378.

Calantone, R.J., Di Benedetto, A., Stank, T.P. 2005. Managing the supply chain implications of launch. ***The PDMA Handbook of New Product Development 2nd edition***. 2005. New Jersey: John Wiley & Sons

Chiu, M. C., Okudan, G. E. 2010. A small to medium-size enterprise oriented methodology for optimizing product and supply chain decisions. ***Proceedings of the ASME 2010 International Design Engineering Technical Conferences & Computers and Information in Engineering Conference*** IDETC/CIE 2010 August 15-18, 2010, Montreal, Quebec, Canada

Christensen, C. M., & Raynor, M. E. 2003. ***The innovator's solution: Creating and sustaining successful growth.*** Boston: Harvard Business School Press.

Clark, K. B., & Fujimoto, T. 1991. ***Product development performance: Strategy, organization and management in the world auto industry***. Boston: HBS Press.

Crawford, M., & Di Benedetto, A. 2008. ***New products management***. New York: McGraw-Hill.

Croxton, K. L. 2003. The order fulfillment process. ***The International Journal of Logistics Management***, 14(1): 19-33.

Dean, T. J. 1995. ***New venture formations in United States Manufacturing: The role of industry environments***. New York: Garland Publishing.

Dess, G. G., & Beard, D. W. 1984. Dimensions of organizational task environments. ***Administrative Science Quarterly***, 29(1): 52-73.

Edelmann, L., & Yli-Renko, H. 2010. The impact of environment and entrepreneurial perceptions on venture-creation efforts: Bridging the discovery and creation views of entrepreneurship. ***Entrepreneurship Theory and Practice***, 34(5): 833–856.

Ernst, H. 2002. Success factors of new product development: A review of the empirical literature. ***International Journal of Management Reviews***, 4(1): 1-40.

Fine, C.H. 1998. ***Clockspeed - Winning industry control in the age of temporary advantage***. Reading, MA: Perseus Books,.

Fine, C. H., Golany, B., Naseraldin, H. 2005. Modeling tradeoffs in three-dimensional concurrent engineering: a goal programming approach. ***Journal of Operations Management***, 23: 389-403.

Fisher, M. L 1997. What is the right supply chain for your product? A simple framework can help you figure out the answer. ***Harvard Business Review***, 75(2): 105-116.

Fixson, S. K. 2005. Product architecture assessment: A tool to link product, process and supply chain decisions. ***Journal of Operations Management***, 23: 345-369.

Forza, C., Salvador, F., & Rungtusanatham, M. 2005. Coordinating product design, process design, and supply chain design decisions. Part B. Coordinating approaches, trade-offs, and future research directions. ***Journal of Operations Management***, 23: 319-324.

Grant, R. M. 2010. ***Contemporary strategy analysis***. 7th edition. Hoboken, NJ: John Wiley and Sons.

Gunasekaran, A., Ngai, E. W. T. 2005. Built-to-order supply chain management: a literature review and framework for development. ***Journal of Operations Management***, 23:423-451

Hult, G. T. M., & Swan, K. S. 2003. A research agenda for the nexus of product development and supply chain management processes. ***Journal of Product Innovation Management***, 20(5): 333-336.

Jahnukainen, J., Lahti, M. 1999. Efficient purchasing in make-to-order supply chains. ***International Journal of Production Economics***, 59:103-111.

Kerzner, H. 2001. ***Project management: A systems approach to planning, scheduling, and controlling***. Hoboken, NJ: John Wiley & Sons.

Koufteros, X. A., Cheng, T. C. E., & Lai, K. H. 2007. "Black-box'' and ''gray-box'' supplier integration in product development: Antecedents, consequences and the moderating role of firm size. ***Journal of Operations Management,*** 25: 847-870.

Krishnan, V. & Ulrich, K. T. 2001. Product development decisions: A review of the literature. ***Management Science,*** 47(1): 1-21.

Lau, A. K. W., Yam, R. C. M., & Tang, E. 2007. The impacts of product modularity on competitive capabilities and performance: An empirical study. ***International Journal of Production Economics,*** 105(1): 1-20.

Mendelson, H., Pillai, R. R. 1999. Industry clockspeed: Measurement and operational implications. ***Manufacturing and Service Operations Management***. 1 (1): 1-20

Narasimhan, R., Kim, S.W., Tan, K.C. 2006. An empirical investigation of supply chain strategy typologies and relationships to performance. ***International Journal of Production Research***. 2006: 1-29

Novak, S., & Eppinger, S. D. 2001. Sourcing by design: Product complexity and the supply chain. ***Management Science***, 47(1): 189.

Olhager, J., Wikner, J. 1998. A framework for integrated material and capacity based master scheduling, in Drexl A and Kimms A (Eds), ***Beyond Manufacturing Resource Planning (MRPII) – Advanced Models and Methods for Production Planning***, Springer Verlag, pp. 3-20.

Olhager, J. 2003. Strategic positioning of the order penetration point. ***International Journal of Production Economics,*** 85(3): 319-329.

Pimmler, T.U., Eppinger, S.D. 1994. Integration analysis of product decompositions. Working Paper # 3690-94-MS. ***MIT Sloan School of Management***, Cambridge, MA, p. 39.

Safizadeh, M.H., Ritzman, L.P., Sharma, D., Wood, C. 1996. An empirical analysis of the product-process matrix. ***Management Science,*** 42 (11): 1576

Searcy, T. 2008. Companies don't compete, supply chains compete. ***http://answernet.wordpress.com/2008/11/24/companies-dont-compete-supply-chains-compete***

Seidel, M., Loch, C. H. Chahil, S. 2005. Quo vadis, Automotive Industry? A vision of possible industry transformations. ***Working paper series INSEAD***. 2005/58/TOM

Simchi Levi, D., Simchi-Levi, E., & Kaminski, P. 2008. ***Designing and managing the supply chain***. New York: McGraw-Hill.

Sosa, M. E., Eppinger, S. D., Rowles, C. M. 2004. The misalignment product architecture and organizational structure complex product development. ***Management Science***, 50(12): 1674-1689.

Srivastava, R. K., Shervani, T. A., & Fahey, L. 1999. Marketing, business processes, and shareholder value: An organizationally embedded view of marketing activities and the discipline of marketing. ***Journal of Marketing,*** 63: 168-179.

Stavrulaki, E., & Davis, M. 2010. Aligning products with supply chain processes and strategy. ***International Journal of Logistics Management,*** 21(1): 127-151.

Supply Chain Council. 2008. ***Supply chain operations reference model, SCOR 9.0*** www.supply-chain.org

Tatikonda, M. V., & Stock, G. N. 2003. Product technology transfer in the upstream supply chain. ***Journal of Product Innovation Management***, 20(6): 444-467.

Teece, D. J. 1986. Transaction cost economics and the multinational enterprise. ***Journal of Economic Behavior and Organization*, **7: 21-45.

Thaler, K. 2003. ***Supply chain management: Prozessoptimierungen in der logistischen kette***. Troisdorf, Germany: Fortis im Bildungsverlag EINS.

Ulrich, K. 1995. The role of product architecture in the manufacturing firm. ***Research Policy*** 1995 Vol.24

Ulrich, K., & Eppinger, S. D. 2011. ***Product design and development***. New York: McGraw-Hill.

Vachon, S., Halley, A., Beaulieu, M. 2009. Aligning competitive priorities in the supply chain: the role of interaction with suppliers. ***International Journal of Operations and Production Management***, 29 (4): 322-340

Vonderembse, M. A., Uppal, M., Hunag, S. H., Dismukes, J.P. 2006. Designing supply chains: Toward theory development. ***International Journal of Production Economics***, 100: 223-238.

Wheelwright, S. C., & Clark, K. B. 1992. ***Revolutionizing product development.*** New York: The free press.

Appendix 4.A: List of NAICS codes of products in the sample

Observation No.	NAICS Code	Observation No.	NAICS Code
1	334510	65	339114
2	334514	67	339113
5	339112	68	334510
7	339114	70	325211
11	339116	71	311514
12	323117	73	335911
14	339112	75	325199
15	3273320	76	333618
17	3345111	80	Confidential
18	325412	82	325211
19	334413	84	311514
20	333999	90	335911
22	334511	91	311514
23	311920	92	325199
24	335314	132	333618
25	339112	133	334511
28	339932	134	339932
30	333913	135	339932
32	333111	16	323117
34	311999		
36	311991		
40	332420		
41	332420		
42	334613		
44	334510		
45	339112		
49	334510		
50	339112		
51	339312		
52	339312		
54	334310		
59	339114		
60	334310		
63	339112		

VITA

Dirk J. Primus entered the PhD program at Bentley University in 2008 with degrees in Chemical/Bioprocess Engineering from University of Nuremberg, in Microbiology from University College Cork/Ireland and an Executive MBA in Entrepreneurial Management from Steinbeis University/Berlin. Dirk J. Primus has 15 years of experience as a practitioner, mostly at the managerial-level, in the Life Sciences Industry. He worked for Johnson & Johnson, Fresenius Pro Serve, Life Sciences International and most recently for Pall Life Sciences. Since August 2012, he works in the Management Department at Bryant University, where he teaches Strategy and International Business.

Permanent Address: 23 Paul Gore Street #3, Jamaica Plain, MA 02130

This manuscript was typed by the author.