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PRODUCTION & MANUFACTURING | RESEARCH ARTICLE

Integrating product design into the supply chain

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Abstract: *Purpose:* The aim of the research is to illustrate how companies can create competitive capabilities through integration of product design into the supply chain. In doing so the paper reveals the challenges and the opportunities that companies face when integrating product design and supply chain. *Design/Methodology/Approach:* The research is case based and focuses on six companies. Ten interviews were carried out in each of these with senior managers. The Resource-Based View (RBV) is utilised to put these empirical findings into a theoretical context. *Findings:* The findings reveal a range of opportunities and challenges when integrating product design and the supply chain and subsequently a step-by-step guide is developed to address these. *Practical Implications:* The research provides key recommendations to companies on how to create competitive capabilities by integrating product design into the supply chain. *Originality/Value:* This paper provides novel insights to both practitioners and researchers. For practitioners detailed recommendations are given on how they can maximise benefits through integrating product design into the supply chain. The RBV has been harnessed to highlight how integration needs to be balanced with the company's current resources and capabilities.

Subjects: Industrial Design; Manufacturing Engineering Design; Supply Chain Management

Keywords: product design; globalisation; supply chain

1. Introduction

In an increasingly globalised and inter-connected world the product development process has become globally distributed with activities spread out both physically and at times also to different



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Omera Khan is a Full Professor in Operations and Supply Chain Management at Aalborg University Copenhagen and has a key role in advancing the group's strength in logistics and supply chain research, education and business provision. She is also a Visiting Professor at Royal Holloway University of London and has held visiting positions at MIT (USA) MBS (UK) SP Jain (Dubai and Singapore). During her career she has supervised several Masters, MBA and PhD theses to successful completion.

Omera has gained international recognition for her research in supply chain risk management. She has led and conducted research projects, in supply chain resilience, responsiveness, sustainability, cyber risk and security and the impact of product design on the supply chain. In addition Omera works with leading organisations on a range of supply chain and logistics issues and is advisor to many Universities developing courses in logistics, supply chain and operations management.

PUBLIC INTEREST STATEMENT

Given that one of the most striking trends to emerge in the last decade is the increased customisation and service expected by the end customer, the supply chain must be more customer-centric rather than product centric. This requires us to fundamentally change the way we have traditionally managed our operations, which were sequential, longer and leaner. Today's supply chains must be more flexible, adaptable and agile to respond quickly to customer demands. Design is a key competitive capability that is often neglected in the management of supply chains, yet research shows its significance can carry up to 80% of the costs and subsequent complexity in supply chains. In our paper we argue for the importance of integrating product design in the supply chain to build the competitive capabilities that are required to survive in what has become the new normal operating environment.

suppliers (Hansen & Ahmed-Kristensen, 2011; Hansen, Zhang, & Ahmed-Kristensen, 2013). In light of this development previous research has focused on different elements of the product design phase; risk evaluation, sustainability, material selection, design approaches, organisation and design changes to mention a few (Bonvoisin, Halstenberg, Buchert, & Stark, 2016; David, 2013; Eddy, Krishnamurty, Grosse, Wileden, & Lewis, 2013, 2015; Goswami & Tiwari, 2014; Liu & Boyle, 2009; Morris, Halpern, Setchi, & Prickett, 2016; Sheldon, 2004).

However, many companies continue to fail to understand that decisions taken at the product design stage can have a critical impact on through life costs, agility and supply chain risk (Khan, Christopher, & Burnes, 2008; Krishnan & Ulrich, 2001). Therefore the need to integrate product design decisions, which is usually the domain of engineers into the supply chain management process emerges. The integration of product design into the supply chain provides companies with a strategy to sustainably establish a competitive advantage in increasingly volatile and competitive global markets (Heim & Peng, 2010; Khan, Christopher, & Creazza, 2012; Pagell, 2004).

A critical review of the literature has revealed that a significant amount of information exists on the opportunities and challenges of integrating business functions (Chen & Paulraj, 2004; Christopher & Holweg, 2011; Ding, Guo, & Liu, 2011; Ellram, Tate, & Carter, 2007; Holmberg, 2000; Holweg, Disney, Holmström, & Småros, 2005). However, the increasing importance of product design in relation to supply chain decisions have seen limited research focus (Khan et al., 2008, 2012). This is not surprising given the silo nature of organisations with product design engineers working in isolation to other business functions such as procurement, marketing and logistics, which are integral to the competitiveness and success of a supply chain. The research community has demanded more empirically-based research (see for example Khan et al. (2012) and Kristianto, Gunasekaran, Helo, and Sandhu (2012)). This paper addresses this need by employing a multiple case study approach. This allows for empirically driven comparative insights into how best to conduct the integration of product design into the supply chain along with the inherent benefits and challenges in doing so. Specifically, the purpose of this paper is to illustrate how companies can create competitive capabilities through integrating product design into the supply chain. This is presented through an analysis of the opportunities and challenges of integrating product design and the supply chain as a basis for establishing sustainable competitiveness in increasingly complex customer markets.¹ The theoretical lenses used to analyze the findings are the Resource-Based View (RBV). This allows us to analyze the tangible and intangible resources within the supply chain in order to suggest recommendations, which can help establish sustainable competitive abilities through integrating design into the supply chain.

The key contribution of this paper is the detailed recommendations for maximizing the benefits of integrating product design into the supply chain. More specifically, it highlights how the integration of product design into the supply chain increases communication, supply chain visibility, responsiveness as well as the reduction of supply chain risk, all of which are key to maximizing and sustaining business performance. Moreover, the paper features a step-by-step guide on how to harness the benefits of integrating product design into the supply chain.

To address the research aim the next section explores relevant literature. Section 3 outlines the research methodology employed for the research, whilst Section 4 presents the findings of the research, which is followed by the development of the guide and theoretical inferences. The paper concludes by summarizing the key findings and outlines the limitations and future directions for research in the field.

2. Literature review

This session presents the opportunities and challenges companies face when integrating product design and the supply chain. Furthermore, the RBV is used as a theoretical framework wherein to view this development. Firstly, though, we debate the theoretical backdrop on which the integration of product design and the supply chain takes place.

2.1. The responsive—and efficient—supply chain

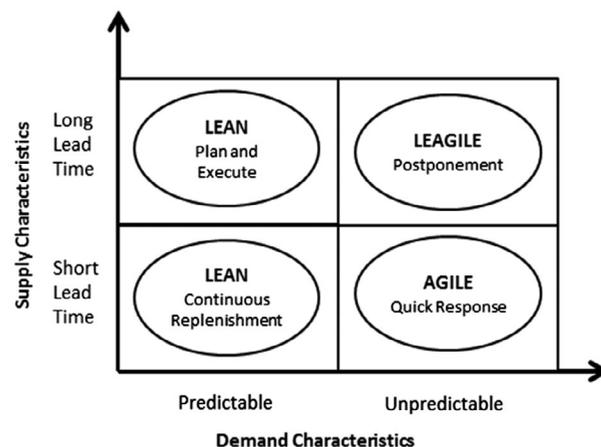
Research has focused on the characteristics of supply chain management in terms of performance (see for example Garcia-Arca & Prado-Prado, 2010; Mendonça Tachizawa & Giménez Thomsen, 2007; Van Donk & Van der Vaart, 2005). In recent years research has focused on increasing the responsiveness of supply chains by making them agile. An agile supply chain is a supply chain, which can quickly change and adapt to new circumstances, for example new markets, natural disasters, which make certain transport routes difficult or new customer preferences (See for example Christopher & Towill, 2002; Gunasekaran, Lai, & Cheng, 2008; Vonderembse, Uppal, Huang, & Dismukes, 2006). Another approach is a lean supply chain, which favors efficiency and reliability but is low on innovation and takes a long time to change. A recent term, leagile, combines elements of both approaches. When to use which approach, depends on the demand and supply characteristics of the given product (see Figure 1). A predictable demand indicates a lean approach, while unpredictable demand with short lead times should adopt an agile approach to be able to respond quickly while an unpredictable demand with long lead times should adopt a leagile approach.

At this stage it is important to highlight that no matter what approach is chosen coordination and collaboration throughout the supply chain are essential elements. For an agile approach both need to be close and regular, therefore, regular communication and detailed information sharing, so that the supply chain can respond quickly. For a lean approach coordination is essential to ensure everything flows.

Recent research has resulted in a compilation of drivers for supply chain flexibility, based on multiple case studies (Barnes & Lea-Greenwood, 2006; Lee, 2004; Mendonça Tachizawa & Giménez Thomsen, 2007; Meredith & Francis, 2000). These include (note that this list is not exclusive):

- Suitable supplier selection.
- Long-term relationships with suppliers.
- Development of Third Party Logistics (3PLs).
- Alternative transportation modes.
- Joint product development with suppliers.
- Suppliers certification and development.
- Supplier quality management programmes.
- Inventory buffers.
- Outsourcing.
- De-coupling and postponement points.
- Modularity.

Figure 1. Characteristics of lean, agile and leagile supply chains.



- Standardisation.
- Advanced technologies in the design (CAD, CAM, ...).
- Information systems based on barcodes, EDI or RFID.

In order to debate the integration of product design into the supply chain, the above mentioned drivers should be considered.

In summary, integrating product design into the supply chain can be done in different ways, using different types and levels of coordination and collaboration throughout the supply chain, depending on the chosen approach—which again depend on the specific supply and demand characteristics for the specific supply chain.

2.2. Integrating product design and the supply chain: the opportunities

Literature describes that the integration of product design and supply chain functions, provides opportunities for the reduction of production costs, the compression of time-to-market, a higher proficiency of serving customers, as well as it reduces supply chain risks (Demeter, 2012; Petersen, Handfield, & Ragatz, 2003; Pusa & Rajshekar, 2004).

Introducing concurrent design and adhering to supply chain capacities and capabilities reduces supply chain risks such as designing products the supply chain may not be able to produce fast enough, well enough or cannot deliver appropriately (Jüttner, 2005). Thus by consciously considering and adhering to supply chain capabilities and capacities, supply chains can minimise certain risks associated with customer dissatisfaction from an early stage (Faisal, Banwet, & Shankar, 2006). Literature suggests that a more intimate understanding of the supply chain capacities and capabilities can minimise the lead-time from concept to production and ultimately the shelf. This is made possible as more processes may be undertaken concurrently (Khan & Creazza, 2009) by way of enhancing the visibility of the capacities and capabilities through integration. A view supported by the three dimensional, concurrent engineering (3DCE) approach devised by Fine (1998). Thus, by means of reducing sequential and linear processes, valuable time to market can be saved (Khan & Creazza, 2009).

Furthermore, by integrating product design more effectively into the supply chain, costly redesigns due to new customer expectations or a change in requirements, such as in the case of Airbus A380's development process, can be reduced significantly as well as overall production time can be minimised (Pusa & Rajshekar, 2004).

The ability to respond more quickly to customer requirements through more rapid development of new products and services in combination with the effective movement of these through the supply chain presents a powerful competitive advantage (Blackburn, 2012; Stalk & Hout, 1990) to companies in volatile markets. Thus the ability to compress time in the supply chain, by means of integrating certain functions, allows companies to become more agile, enabling these to respond to disruptions more rapidly (Demeter, 2012; Stalk & Hout, 1990; Zsidisin & Smith, 2005).

Beyond the above opportunities, it is also suggested that the integration of functions across a supply chain may increase supply chain performance through understanding supply chain collaborators to a higher level and thus are enabled to assist each other more effectively (Carr & Pearson, 1999; Goffin, Lemke, & Szwejczewski, 2006; Koçoğlu, İmamoğlu, İnce, & Keskin, 2011).

2.3. Integrating product design into the supply chain: the challenges

Despite the significant benefits inherent in the integration of product design into the supply chain, there are also substantial challenges regarding this process as well as the continuous conduct of the strategy (Cousins & Menguc, 2006; Lin & Zhou, 2011).

A key challenge of integrating product design into the supply chain is that functions are often managed in isolation of other functions (Ballou, Gilbert, & Mukherjee, 2000). In fact, product design is often neglected in the strategic management of a supply chain (Doyle & Broadbridge, 1999). Thus an attempt to change this relationship will require a fundamental change in the way organisations have performed certain processes for decades.

Exacerbating this challenge, the goals amongst functions of a business or different businesses are often dissimilar (Ding et al., 2011). Hence the maximization of benefits between functions or businesses are often contradictory (Ding et al., 2011), making it difficult to generate mutually inclusive benefits by working together more closely (Ding et al., 2011).

Beyond the challenges to the internal integration, there are further challenges to the external integration of suppliers and customers. Literature suggests that the integration of upstream tiers is largely underdeveloped. It appears that in most cases the upstream relationships are limited to the monetary, material or order exchanges (Ding et al., 2011; Fawcett & Magnan, 2002). Arguably, this is a far cry from the intertwined way of collaborating that is necessary for the proposed strategy to work (Petersen, Handfield, & Ragatz, 2005).

A significant challenge in the pursuit of the strategy is in many cases the geographical distance of supply chain partners or their functions (Barson et al., 2000; Narasimhan & Nair, 2005; Terwiesch, Bohn, & Chea, 2001). Moreover, as supply chains have extended and have become increasingly dispersed geographically, supply chains have arguably distanced themselves from their respective market places in recent years (Khan & Creazza, 2009). This, according to Holmström, Korhonen, Laiho, and Hartiala (2006) complicates effective collaboration and increases the risk profile of such supply chains.

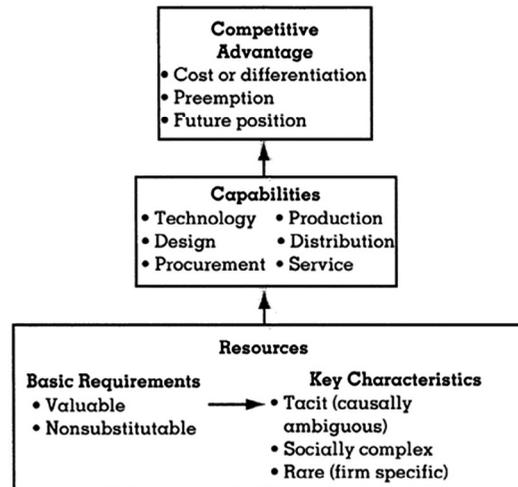
Further fundamental challenges revolve around the fear of industrial espionage, complicating the external integration process (Ballou et al., 2000; Barson et al., 2000). This argument is highly relevant in relation to the proposed strategy as in some cases external functions would be integrated into businesses, providing access to commercially sensitive data. Nonetheless, Quesada, Rachamadugu, Gonzalez, and Martinez (2008), maintain that a key strategy to establishing competitive advantages in volatile markets, is to undergo external supply chain integration to focus the capabilities of the wider supply chain.

Having outlined a number of challenges concerned with the integration of functions of upstream tiers, it is also important to consider integration challenges concerning customers (Ding et al., 2011; Lakemond & Berggren, 2006; Sandmeier, Morrison, & Gassmann, 2010). Similarly to the geographic challenges regarding the integration of upstream functions, closeness to customers is also classed as positive determinant for increasing market share (Tan, Lyman, & Wisner, 2002). Furthermore, it is becoming increasingly important for customers to be integrated in the design processes so that design teams are able to pick up customer trends more rapidly (Barratt, 2004; Lummus, Krumwiede, & Vokurka, 2001; Sandmeier et al., 2010). Despite the benefits of different types of integration Cousins and Menguc (2006), maintain that any type of integration can prove to be highly challenging.

2.4. RBV

RBV is a theory, which suggests that a company's competitive advantage is connected to its internal resources. An extension of this view is the knowledge-based view of the firm, which considers knowledge the most significant resource a company can have (Grant, 1996). The RBV of the firm is said to be the dominant theory for explaining differences in performance among firms today (Barney, Wright, & Ketchen, 2001; Connelly, Ketchen, & Slater, 2011).

Figure 2. RBV based on (Hart, 1995).



The RBV highlights that firms are a bundle of resources and that competitive advantage comes from resources and capabilities (Colotla, 2003). Figure 2 show elements of resources and capabilities and how these contribute towards building competitive advantages.

Resources are often described by nouns, and may be classified into tangible (financial and physical), intangible (technology, reputation and culture), and human (specialised skills and knowledge, communication and motivation) (Grant, 2002).

Capabilities can then be defined in terms of resources and are a result of complex patterns of interactions and coordination between resources. Capabilities are often described by verbs. Grant (1991) views capabilities as “organisational routines”, which are “regular and predictable patterns of activity which are made up of a sequence of coordinated actions by individuals”. Examples of capabilities are product development, pricing, marketing communications, selling, and market information management capabilities (Vorhies & Morgan, 2005).

The value of resources and capabilities depends on the market a firm operates in (Barney, 2001), the rarity, inimitability, and substitutability of resources and capabilities—which depends on the extent to which they are developed in unique historical circumstances (Dierickx & Cool, 1989), path dependent (Arthur, 1989), causally ambiguous (Lippman & Rumelt, 1982; Reed & DeFillippi, 1990), socially complex (Barney, 1986), intangible (Polanyi, 1962), invisible (Itami, 1987), or are bundled together in complex ways (Barney, 2011; Dierickx & Cool, 1989).

A company can create economic gain through:

- (1) Resource-picking; choosing superior resources (Makadok, 2001).
- (2) Capability building; being more effective than competitors at deploying resources (Makadok, 2001).

Using this theoretical perspective it is in the firm’s best interest to gather as many and the best resources and capabilities. Furthermore, it becomes a key duty for managers to structure, bundle, and leverage their resources in ways that maximise their contribution towards providing competitive advantage for the company (Sirmon, Hitt, & Ireland, 2007).

The use of RBV has been debated in connection with supply chain management (see for example Barney, 2012; Hunt & Davis, 2008, 2012; Ramsay, 2001). The advocates for using the RBV approach have argued that purchasing and supply chain management often have the characteristics that could

lead them to be a source of at least temporary advantage, if not sustained competitive advantage (Barney, 2012; Hunt & Davis, 2012). Empirical evidence to this effect include Walmart's supply chain management system, which is both socially complex and path dependent, which has been a source of competitive advantage for Walmart from at least since the 1960s (Ghemawat, 1986). Toyota's purchasing system, a system that has helped Toyota implement its lean manufacturing approach, has both path dependent and tacit attributes (Iyer, Seshadri, & Vasher, 2009). For other empirical examples of competitive advantages gained through supply chain management and procurement we refer to Azadegan (2011); Hartmann and De Grahl (2011); Hitt (2011) and Paulraj (2011).

3. Methodology

To guide the research we use the literature review to develop concrete research questions. The literature review has revealed that whilst the effective integration of product design into the supply chain offers various opportunities such as risk mitigation, cost savings, serving customers more effectively, offering opportunities for time-based competition (amongst others), the strategy also harbors a diverse range of challenges. These include generic challenges around relationship management, organizational versus supply chain foci, the current management of functions as well as fears of industrial espionage to name a few.

It transpired that the challenges of integrating product design and supply chain can be classified into internal and external challenges. Moreover, internal challenges arise from within an organization, whilst external challenges are concerned with challenges from the wider supply chain environment, its configuration and orchestration, as exhibited in Table 1, which summarises the opportunities and challenges of integrating product design and the supply chain according to prominent literature.

The review of the RBV of the firm showed that supply chain management, including product design in the supply chain as well as distribution and procurement can be key capabilities in developing competitive advantage for a company. However, these capabilities rely on valuable and in exchangeable resources. Therefore, integrating product design with the supply chain can become a competitive advantage for the company given it has the resources and capabilities necessary to be competitive in the given market. To archive this managers needs to structure, bundle, and leverage the resources and capabilities in such a way that a competitive advantage is archived.

Despite this information being represented in literature, it has not been confirmed through empirical research that focuses on the opportunities and challenges specifically. As mentioned in the introductory section, this paper addresses this gap in the extant body of knowledge.

The findings from extant literature shown in Table 1 is validated and expanded on through the empirical findings from in-depth and detailed case studies across industries and cultures. We can now formulate the following research questions we seek to address through the case studies:

- Research question 1: What are the opportunities of integrating product design and the supply chain?
- Research question 2: What are the challenges of integrating product design and the supply chain?
- Research question 3: How can companies maximise the opportunities of integrating product design into the supply chain?

To investigate the research questions a multiple case study approach was adopted. Since the research methodology is contingent to the problem investigated and to the progress of knowledge on a specific subject (Danese, 2006), the methodological choice is informed by the way the research questions are phrased (Yin, 2013). This choice is reflected and justified in the subjective nature of the research (Dey, 1993), as well as the inductive nature of the research (Bryman & Bell, 2007).

Table 1. Opportunities and challenges of integrating product design and the supply chain according to prominent literature

Literature evidence	References
Opportunities	
Reduction of production costs	Hum and Sim (1996); Petersen et al. (2005); Pusa and Rajshekar (2004); Khan and Creazza (2009)
Compression of time-to-market	Demeter (2012); Fine (1998); Hum and Sim (1996); Jüttner (2005); Khan and Creazza (2009); Mason-Jones and Towill (1998); Stalk and Hout (1990)
Proficiency of serving customers	Barros, Barbosa-Póvoa, and Blanco (2013); Blackburn (2012); Demeter (2012); Faisal et al. (2006); Stalk and Hout (1990)
Reduction of supply chain risks	Demeter (2012); Jüttner (2005); Khan and Creazza (2009); Mason-Jones and Towill (1998); Pusa and Rajshekar (2004); Zsidisin and Smith (2005)
Challenges	
<i>Internal challenges</i>	
Isolation of functions	Ballou et al. (2000); Cousins and Menguc (2006); Doyle and Broadbridge (1999); Kotler and Rath (1984)
Generation of mutually inclusive benefits	Ding et al. (2011); Doyle and Broadbridge (1999); Kotler and Rath (1984)
<i>External challenges</i>	
Integration of upstream tiers	Barratt (2004); Ding et al. (2011); Fawcett and Magnan (2002); Lummus et al. (2001); Petersen et al. (2005); Quesada et al. (2008); Tan et al. (2002); Van Hoek, Harrison, and Christopher (2001); Wagner and Hoegl (2006)
Integration of customers	Barratt (2004); Ding et al. (2011); Kaulio (1998); Lakemond and Berggren (2006); Lummus et al. (2001); Sandmeier et al. (2010); Sharifi and Pawar (2002); Tan et al. (2002); Van Hoek et al. (2001)
Geographical distance of SC partners	Barson et al. (2000); Holmström et al. (2006); Khan and Creazza (2009); Narasimhan and Nair (2005); Sharifi and Pawar (2002); Tan et al. (2002); Terwiesch et al. (2001)
Industrial espionage	Barson et al. (2000); Ballou et al. (2000); Quesada et al. (2008)

Furthermore, the chosen approach is consistent with other leading authors in the field of demand chain and supply chain management (Chen & Chiang, 2011; Jüttner, Godsell, & Christopher, 2006; Seuring, 2008).

Six cases, representative of six different global supply chains were selected following a purposive sampling technique, and investigated in depth. The sample size was informed by recommendations from Yin (2013), who recommends 5–6 case studies in order to generate theory building and in order to explore specific aspects of a phenomenon where some knowledge about the phenomenon is known.

Based on these indications, cases were selected purposively to enable the response to the research questions in pursuit of meeting the objectives of the research (Saunders, Lewis, & Thornhill, 2007). Therefore all cases were used to address all three research questions. The criteria for cases included that companies were similarly sized and operate a product design department. Please see Table 2 for a sample case description (company names have been anonymised for confidentiality purposes).

Data collection predominantly revolved around semi-structured interviews to enable replication across all cases, whilst allowing the pursuit of unexpected lines of enquiry (Grix, 2001; Yin, 2013). The interview protocol constituted four distinctive sections comprising of questions generating data to answer the research questions. Sections revolved around the company background, the product design process as well as the interface between product design and the supply chain, where challenges and opportunities of integrating product design and the supply chain were discussed.

Table 2. Sample case description

Company name	Industry	Product
Sireneco (Global company)	Alarm system-manufacturer	Alarm and fleet control systems for automotive manufacturers
Interco (Global company)	Non-woven textile supplier	Non-woven textiles for automotive interiors
Rubberco (Global company)	Footwear rubber-manufacturer	Rubber soles for outdoor, work, fashion and orthopedic applications
Plastco (Global company)	Plastic polymer-manufacturer	Plastic polymer membranes and laminates for sport, law enforcement and military apparel.
Texco (Global company)	Textile-manufacturer	Cashmere garments and blankets, merino, silk and cotton products
Wallco (Global company)	Ceramic tile manufacturer	Wall tiles for retailers, DIY and house developers

In total 60 interviews was carried out, ten in each case company, to achieve theoretical saturation and involved managers from different hierarchical levels and functions. These included CEOs, product design and development managers, supply chain and sourcing managers, operations managers as well as marketing managers.

The data from interviews was supplemented with additional company documentation and was triangulated by researcher observation. Inconsistencies among different sources of information were investigated by means of follow-up interviews.

Cases were analysed following the framework for analyzing case studies provided by Creswell (2007) and employed template analysis (King, 2004) as a technique to analyzing the data. The dataset was coded and themed using thematic analysis (King, 2004), to identify emergent themes, patterns of commonality and key differences among them (Ghauri, 2004). To establish an in-depth understanding of six different cases, each case was reviewed individually and summarised in individual case reports.

Following this, a detailed summary report outlining similarities and differences between cases (based on the cross-case analysis) was produced, forming the basis for theoretical inferences.

The rigour and the quality of the research were established adhering to the four quality measures proposed by Yin (2013) including construct-, internal-, external-validity and reliability. Thus to ensure a high level of scientific rigour, different measures were employed during different stages of the research, as depicted in Table 3. In order to maximise the quality of the case study approach, recommendations by Mota Pedrosa, Näslund, and Jasmand (2012) have been applied.

This study makes use of theory-building from case studies. Its strengths are novelty, testability, and empirical validity, which arise from the intimate linkage with empirical evidence (Eisenhardt, 1989; Ellram, 1996; Yin, 2013). The process has eight steps Eisenhardt (1989):

- (1) Getting started.
- (2) Selecting cases.
- (3) Crafting instruments and protocols.
- (4) Entering the field.
- (5) Analyzing data.

Table 3. Overview of the validity and reliability of the research, adapted from COSMOS Corporation, as cited in Yin (2013)

	Tactic	Research phase	Action taken
Construct validity	Multiple	Data collection	Undertake interviews and review additional documentation
	Chain of evidence	Data collection	Recorded and transcribed interviews along with notes
	Participants review draft	Write-up	Case reports were reviewed by research participants
Internal validity	Pattern matching	Data analysis	Patterns were identified across data
	Explanation building	Data analysis	Areas were reciprocally explanatory
	Content analysis	Data analysis	Analysis was based on interview transcripts
External validity	Alternate theories within single cases	Research design	Alternate theories were evaluated against findings
	Replication logic in multiple cases	Research design	Logic was cross matched between cases
Reliability	Interview protocol	Data collection	Interviews were undertaken in an identical fashion
	Case database	Data collection	All findings were entered into a database

- (6) Shaping hypotheses.
- (7) Enfolding literature.
- (8) Reaching closure.

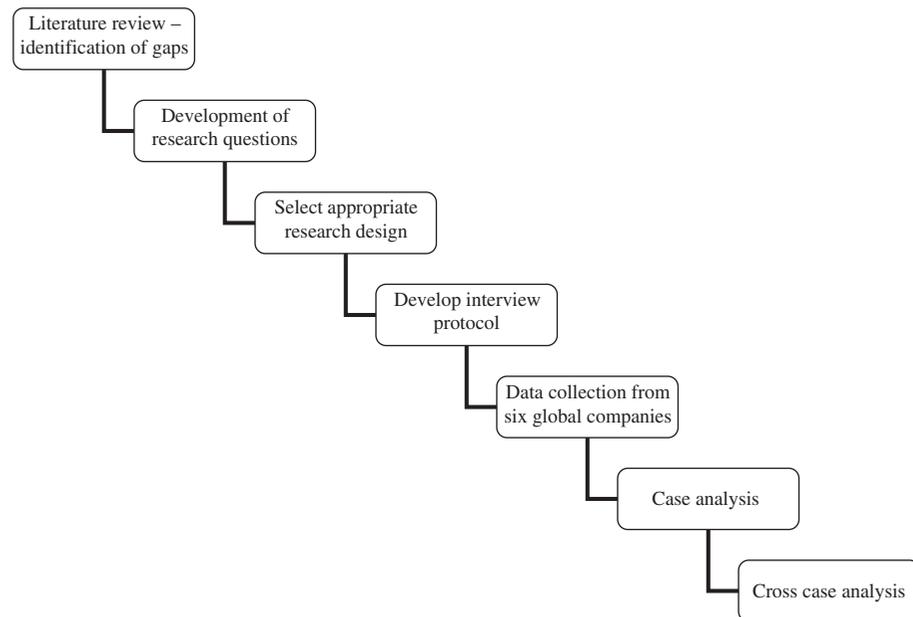
As described in this chapter the process starts with investigating previous literature and formulating research questions. The case selection, data gathering and data analyses follows. Hereafter it becomes possible to categorise the findings and compare them with previous findings and finally to make conclusions based on this analysis. Figure 3 illustrates the key stages in the research methodology.

Based on the choice of methodology including the case choices, the generalizability of the study is deemed high. This is as the selected cases have been chosen specifically as they are representative of their industries. Table 4 displays the types of data that were collected from each case company. As a result, the findings are highly applicable to other companies who can learn from the studied cases (Flyvbjerg, 2006). A part of the validation for this research was therefore to present companies with the results and inquire whether these recommendations were useful to them. The generalizability of these results were validated as the companies confirmed the usefulness of the findings for them in terms of creating competitive capabilities through integrating design into the supply chain.

4. Findings

The results of the study are discussed in three sections which are based on the research questions and are centered around Table 4 which shows the opportunities of the integration of product design and the supply chain according to the sample companies' experience, outlining how companies can maximise the opportunities of integrating product design and the supply chain and create competitive capabilities. Note that a positive sign indicates the given case company is making use of the opportunity in question with a positive outcome, a negative sign indicates the given case company is making

Figure 3. Stages in research methodology.



use of the opportunity in question with a negative outcome while a combined positive and negative sign indicate a neutral outcome for the given case company with that opportunity. It should also be noted that the table summarises the findings. What are showcased in Table 5 are the most interesting results from each company (meaning repeated results between the case companies are not shown in the table to ease readability and increase focus on each unique finding in the data-set).

4.1. RQ1: what are the opportunities of integrating product design and the supply chain?

4.1.1. Reduction of production cost

Data obtained from interviews with Plastco as well as Rubberco, revealed that the integration of product design and the supply chain enabled the optimization of production plans and schedules in these companies and thus reduce production costs. This finding is consistent with previous research studies (Christopher & Lee, 2004; Petersen et al., 2005). Another finding which is supported by previous research (Jüttner, 2005; Khan & Creazza, 2009) revealed that effective information sharing and

Table 4. Types of data collected

Company name	Types of data collected
Sireneco	Interviews, observation
	Archival documents, annual report and business strategy reports
Interco	Interviews, observation
	Company documents, annual reports
Rubberco	Interviews, observation
	Annual report
Plastco	Interviews, observation
	Archival documents, finance reports
Texco	Interviews, observation
	Archival documents
Wallco	Interviews, observation
	Annual report and business strategy reports

Table 5. Opportunities of the integration of product design and the supply chain according to sample companies' experience

Company name	Reduction of production costs	Compression of time-to-market	Proficiency of serving customers	Reduction of supply chain risks
Sireneco	(+) Advanced knowledge of technical features for securing purchases of components; reduce purchasing unit costs of components	(+) "Fast track" for the supply of the moulded plastics (3 week supply lead time saving)	(-) Notwithstanding the presence of the product champion, vehicles often present some "hidden" compatibility problems that, often unknown or not pointed out can create pitfalls in serving customers.	(±) Integration allows coping with demand variability and components availability. However, sudden changes can result in longer set-up times with potential shortage of production/delivery capacity
Interco	(-) Poor production process flexibility; missed opportunity to reduce purchasing unit costs of raw materials	(-) Lost opportunity to compress time due to sequential product design process and lack of communication and integration among functions.	(-) Difficulties to vary the production rhythms and to adapt to new market demands. This is also due to the lack of visibility on the actual market demand and customers' needs	(-) Poor data and information sharing leading to a poorly responsive supply chain
Rubberco	(+) Reduction of scraps, capacity to handle variations	(+) Reduction of the sampling time (e.g. from 18 to 5 days for the most innovative produced sole)	(+) Better alignment to customers' expectations in terms of service level led to expansion of the market share in the US; installation of a new technological centre for R&D to rapidly react to customer requirements	(+) Integration of product design and the SC leading to a higher degree of agility staying closer to customers (establishing a R&D centre in China) and implementing a production scheduling optimiser.
Plastco	(+) Reduction of alterations or reduction in unstable design parameters	(+) Reduction of design lead times from 35 to 10 weeks	(+) Lever for gathering crucial customer requirement information for the customization of products at an early stage	(+) Integration of product design and the SC to cope with disruptions in the manufacturing and delivery processes arising through (reduced) changes in the production plan.
Texco	(-) Constrained production capacities	(-) Sampling as a lengthy and costly bottleneck. (+) Tailor aspects of the supply chain to specific features of the product itself (lean vs. agile)	(-) Aligning the sampling activities closely to customer needs is deemed a symptom of a poor integration of functions, leading to a reduced ability to meeting customer requirements.	(+) Integrating design for orchestrating the supply chain; training scheme so that designers spend time confronting with the production/supply chain issues they have to deal with
Wallco	(-) Unfeasibility of productions due to technical constraints neglected in the design phase; products to be redesigned or discarded; constraints in the suppliers' selection	(-) Lost opportunity to compress time due to sequential product design process.	(-) Scarce responsiveness due to long lead times for sourcing products and to unavailability of materials, as well as to lack of internal and external communication	(-) Business working at the very last second within the supply chain; reacting to disruptions connected with capacity constraints only by outsourcing part of the production to its subsidiaries located in the UK

Notes: (+) Positive outcome, (-) Negative outcome and (±) Neutral outcome.

the alignment of design and production processes reduces production costs by way of mitigating the waste of raw materials. This necessitates an innate understanding of the capacities and capabilities of the different functions of the organization and the supply chain.

A further contribution revolves around the fact that companies with a low level of integration among functions in combination with a long lead-time for sourcing materials (such as Texco or Interco) struggled to effectively consider potential sourcing options (i.e. number and location of suppliers) in a timely manner. With respect to this, the data exhibits that this behavior renders organizations to miss out on the optimization of sourcing cost, consequently increasing the cost of production.

4.1.2. *Time-to-market compression*

The data clearly highlight the opportunity to compress time-to-market by effectively integrating product design and the supply chain. The strategic management of the product lead time was an essential element in innovating more responsively to customer demand in markets characterised by short product life-cycles.² The case companies Texco and Sireneco managed the available resources in a more structured fashion, adhering to the complexity of the design process. They evaluated factors such as the number of designers, the time required to design and manufacture products to fulfill demand, and even the meeting the time requirements of customers.

This approach can be enabled by creating a “lattice-amoebic” organizational structure, which implies that no boundary is placed around different parts of an organization. Amongst the cases, this necessitated the close collaboration of product specialists and product range managers, acting as cross-functional teams with suppliers, customers, and retailers. Plastco was able to reduce time-to-market from 35 to 10 weeks by synchronizing different supply chain functions with customer demand, launching products in intervals, and effectively balancing supply chain capacities with customer requirements. Similarly, Rubberco was able to reduce its products sampling time from 18 to 5 days, having a significant impact on time-to-market. This was achieved by orchestrating close collaboration amongst the design-, the technical-, the procurement-, and the manufacturing-teams, as well as suppliers.

The data clearly highlights that by following a lattice-amoebic structure, time-to-market can be compressed significantly.

4.1.3. *Proficiency of serving customers*

The research shows that reducing production costs and compressing time in the supply chain helps companies to match customer requirements—like price and service level—more closely. This is key to success in markets characterised by short product life-cycles and is consistent with previous research (Christopher & Lee, 2004).

Reflecting on the finding, whilst some organizations were able to integrate the different functions more effectively, resulting in an elevated ability to meet customer needs as supported by the literature (Jüttner, 2005; Khan & Creazza, 2009), other cases of the sample struggled with the integration which was reflected in increased product cost and a longer time-to-market, again compliantly to the literature (Cousins & Menguc, 2006; Ding et al., 2011). In these cases such challenges were caused by difficulties in aligning functional and organizational goals.

4.1.4. *Reduction of supply chain risks*

Beyond the above described opportunities through the integration of product design into the supply chain, the data also highlights the ability to reduce risks in the supply chain. This is reflected in the case of Rubberco, where the establishment of a research and development centre in close proximity to the customer market raised the ability to respond to customer demand, reducing the risk of product redesigns, as well as overall production costs. The ability to mitigate the risk of misinterpreting customer demand or requirements is particularly crucial in markets characterised by short product life-cycles.

Moreover, the data exhibited that understanding the capabilities and capacities of a supply chain plays a key role in focusing the upstream tiers of the supply chain on the customer. This is particularly true in the case of Plastco and Sireneco, where the early integration of suppliers enabled effective sourcing of the right raw materials to match customer demand in the future, mitigating numerous risks typically associated with the upstream supply chain which is consistent with previous research (Ragatz & Handfield, 1997; Zsidisin & Smith, 2005).

4.2. RQ2: what are the challenges of integrating product design and supply chain?

The discussion around the challenges of integrating product design and supply chain is split into internal and external challenges and is detailed below. The discussion is centered around Table 6 which depicts an exhaustive summary of how sample companies confronted the challenges of integrating of product design and the supply chain.

4.2.1. Internal challenges

With respect to the internal firm specific challenges, the cases revealed that challenges, relating to the integration of product design and the supply chain, are invariably linked to the organizational structure.

4.2.1.1. *Isolation of functions.* The analysis of the case data revealed that functional silos proved to be a common challenge amongst all cases, which reflects previous findings (Cousins & Menguc, 2006; Ding et al., 2011). Evidence suggests that product design functions rarely share information such as the progress made in the design of products, for instance. Examples for this are the cases of

Table 6. How sample companies confronted the challenges of the integration of product design and the supply chain

Company name	Internal challenges		External challenges			
	Isolation of functions	Mutually inclusive benefits	Integration of upstream tiers	Integration of customers	Geographical distance	Industrial espionage
Sireneco	(+) The chief executive officer acts as a product champion	(+) Dedicated reward system, devised by the CEO, with shared KPIs among functions	(+) Establishment of informal partnership with two suppliers of critical electronic condensers	(-) Confronting this issue by delaying customization of products	(±) Developed an intranet for allowing access to data for SC partners	(+) Patenting the most innovative products and adopting use-licenses for installed components
Interco	(-) Sequential product design process, limited communication between functions	(-) Misalignment of metrics for evaluating product design and supply chain functions	(-) No integration with suppliers	(-) Obtaining information and requirements from customers in a non-proactive way	(-) Passive experience; better outcomes when partners are closely located	(±) Mature adopted technologies, no threat felt about espionage in developing products
Rubberco	(+) Establishment of cross-functional teams made up of all relevant SC functions	(±) No alignment of metrics but overall evaluation on product design process performance	(+) Establish a partnership with key rubber suppliers and production outsourcing experts	(+) Integrate customers to some extent by locating operations physically closer to downstream partners	(+) Establishing an R&D facility in China, closely located to the key SC partners; adoption of real time communication ICT for virtual co-location	(+) Protect innovations by means of registering patents and use-licenses
Plastco	(+) Adoption of the "lattice-amoebic" organisational structure	(±) Independent but non-conflicting evaluation metrics for the principal functions included in the product design process	(+) Secure the sourcing process of polyester for developing new products by selecting few reliable and collaborative suppliers	(+) Order process reengineering for encouraging customers to advance orders and specifications	(+) Adoption of an enterprise-wide planning software with an interface developed to allow selected customers and suppliers to access data (virtual co-location)	(+) Registering patents and reinforcing a very strong brand well known worldwide
Texco	(+) Employ designers acting as project managers	(±) Designers acting as project managers deal with partially aligned metrics for product design and SC functions	(-) No integration with raw materials suppliers	(-) Obtaining information and requirements from customers in a non-proactive way	(-) Distant suppliers mainly represented by sheep farmers.	(+) Secure the supplies of superior quality raw materials and exclusive collaboration with designers
Wallco	(-) Sequential product design process, little cross-functional communication	(-) Misalignment of metrics for product design and SC functions	(-) No integration with raw materials suppliers	(-) Obtaining information and requirements from customers in a non-proactive way	(±) Except for catalogue product suppliers (20%), the other SC partners are mainly local	(±) The threat is felt for its high quality products, not in the design process or for innovations

Notes: (+) positive outcome, (-) negative outcome and (±) neutral outcome.

Interco and Wallco, where a low level of functional integration featured predominantly sequential product design processes and a limited degree of communication between functions during the development of new products.

Generally, the data shows that organizations employing a more structured and formal integration process, yield higher levels of opportunities. This is reflected in the cases of Rubberco and Plastco. Nonetheless, the ability to avoid the risk of lengthy re-designs, re-works, waste production and so forth, was not limited to organizations that are set-up in a lattice-amoebic structure, as in the cases of Sireneco and Texco. Here, relevant managers with sufficient visibility of the supply chain orchestrated the interplay between product design and the wider supply chain.

4.2.1.2. Generation of mutually inclusive benefits. A major challenge to the achievement of a high degree of integration between product design and the supply chain was constituted by the difference in the foci of functions. The findings revealed that this is caused by conflicting key performance indicators of the different functions. Interco, for example, exhibits a close alignment of the product design and sales and marketing functions with a view to achieving time-to-market and sales budget targets collaboratively. The procurement function on the other hand is oriented towards the minimization of raw material costs (forward buying, which may cause a misalignment with respect to the product development lead times and may cause possible variations of technical specifications of new products), whilst the logistics function focuses on the minimization of inventory carrying cost. This fragmented approach results in poor overall integration of the product design process and the supply chain, which implies a minimal ability to adopt concurrent design practices effectively.

4.2.2. External challenges

The external challenges were mainly related to integration of upstream tiers and customer integration, geographical distance and IP rights.

4.2.2.1. Integration of upstream tiers. A key challenge was presented by companies struggling to involve suppliers in the product design process. Fifty percent of the sample companies were largely unable to integrate upstream partners into their product design process, leading to an increased overall production cost, extended time-to-market as well as a periodic inability to serve customers in a timely fashion. In the majority of cases, this was a result of poor relationship management, compromising timely and efficient sourcing of materials.

Plastco, Rubberco and Sireneco, on the other hand were able to rationalise their supplier bases, collaborating more effectively with upstream tiers. More specifically, Sireneco established an informal partnership with two suppliers of critical electronic condensers, whilst Plastco managed to secure the sourcing process of polyester for developing new products by selecting just a few reliable and collaborative suppliers.

4.2.2.2. Integration of customers. Similarly to the integration of suppliers, the integration of customers was also found to be challenging for the majority of the case companies. According to the case companies, the main challenge revolved around a lack of interest of customers in participating in the product design process as the customers "... don't see the advantage of it" as a Supply Chain Manager of Plastco explained.

The only case company that was able to integrate customers to some extent by locating operations physically closer to downstream partners was Rubberco. This organization was able to greatly benefit from integrating customers into its supply chain, as time-to-market could be reduced significantly along with production and product design costs. Moreover, Rubberco was able to develop an innate understanding of relationships with key customers, enabling it to respond more quickly to demand and thereby move towards an agile supply chain.

4.2.2.3. *Geographical distance of SC partners or their functions.* According to the case companies close physical proximity eases the continuous flow of information from source to destination in the product design process. The companies operating in the textile industry such as Texco, Plastco and Rubberco, were particularly reliant on being physically closely situated to suppliers and customers. This was perceived to increase the understanding of customers and suppliers enabling companies to meet customers' needs more effectively, a finding which supports previous findings (Narasimhan & Nair, 2005; Terwiesch et al., 2001).

The research exhibited that in cases where a physical co-location was difficult or not possible, the virtual co-location of teams through information technology solutions presented a good alternative (Plastco and Rubberco).

4.2.2.4. *Industrial espionage.* The majority of the case companies felt that the risk of losing intellectual property was a barrier for the achievement of external integration of product design and the supply chain, particularly for those companies operating in highly technological sectors. For example, operating in a niche market, Rubberco had limited competitors yet the main challenge resided in persuading customers to adopt their special soles for shoe manufacturing instead of copying them or getting them elsewhere as illustrated by this quote by Rubberco's CEO, "Our customers are often our competitors. Sometimes they are replicating our soles. We are a step ahead them, since manufacturing and innovating soles is our core business. However, some of our "classic" products have now become just commodities ... so competitors find it easy to copy those products."

4.2.3. *Creating competitive capabilities through integration of product design into the supply chain*

Having shown the opportunities and challenges in implementing product design in the supply chain we can now address RQ3, which focuses on improvement suggestions. This section will look at practical implications, e.g. the improvements managers can implement and how this relates back to the theoretical framework.

4.3. RQ3: how can companies maximise the opportunities of integrating product design into the supply chain?

Table 7 summarises the recommendations for maximizing opportunities of integrating product design and the supply chain based on the findings from the first two research questions.

A key stage of integrating product design into the supply chain effectively necessitates organizational architectures to remove functional silos and implement cross-functional teams. This transformation led to a decrease in the time-to-market, overall production costs and an improvement of margins for Sireneco, Plastco, Rubberco and Texco. Furthermore, the improvement in communication through the elimination of functional silos enabled concurrent design practices, which improved responsiveness to customers.

Another significant opportunity to maximise benefits from integrating product design and the supply chain resides in the recognition of an organization's supply chain capacities and capabilities. Here the authors refer to the ability of a supply chain to produce products and understand performance capabilities regarding lead-times, volumes, quality and technical attributes realistically. This ability allows organizations to make informed operational decisions about demand fulfillment processes, effectively mitigating downstream supply chain risks and planning resources accordingly. This in-depth visibility, further enhances the ability to integrate suppliers as well as customers in the product design process. This necessitates the generation of synchronised foci and key performance indicators between different partners of the supply chain, which was a significant challenge in the cases. It is essential to identify optimal matches between organizations forming supply networks. Particular challenges pertaining to this are relationship management and intellectual property security.

Table 7. Recommendations for maximizing opportunities of integrating product design and the supply chain

Recommendations	Opportunities	Examples	Challenges	Section reference
Develop a cross-functional approach to the supply chain	Increase in communication and visibility of critical data	Plastco—Adoption of an enterprise-wide planning software with an interface developed to allow selected customers and suppliers to access data (virtual co-location) Rubberco—Establishment of cross-functional teams made up of all relevant supply chain functions; adoption of real time communication ICT for virtual co-location	Aligning focus between relevant functions, particularly across organizational borders	4.1.2; 4.2.1.1
Erode functional silos	Increase in collaboration and focus efforts	Plastco—Adoption of the “lattice-amoebic” organisational structure- Texco—Employ designers acting as project managers	Synchronizing functional key performance indicators and establishing effective communication	4.2.1.1; 4.2.1.2
Integrate key suppliers into the product design process	Increase in responsiveness to customer demand and reduction of supply chain risk	Sireneco—Establishment of informal partnership with two suppliers of critical electronic condensers	Identification of appropriate suppliers and relationship management	4.1.4; 4.2.2.1
Integrate key customers into the product design process	Increase in understanding of customer demand	Plastco—Order process reengineering for encouraging customers to advance orders and specifications	Generate customer interest in collaborating	4.1.4; 4.2.2.2
Recognise the supply chain capacities and capabilities	More informed operational decisions in fulfilling demand and reduction of supply chain risks	Rubberco—Close integration of functions, with detailed understanding of functional abilities	Establishing an overview of capacities and capabilities	4.1.1; 4.1.4
Introduce concurrent design practices	Reduction of time-to-market and production cost	Plastco—orchestrating close collaboration amongst the design team, the technical team, the procurement and manufacturing as well as suppliers	Reorganise the product design process along with production	4.1.2; 4.2.1.2
Locating operations close to key supply chain nodes	Increased visibility of supply and/or demand	Sireneco—Developed an intranet for allowing access to data for SC partners Rubberco—Establishing an R&D facility in China, closely located to the key SC partners; adoption of real time communication ICT for virtual co-location	Applicability (diverse markets, diverse suppliers) and ability (IT and infrastructure)	4.2.2.3
Mitigate against industrial espionage	Reduction of intellectual property risk, increase safety in collaboration	Texco—Secure the supplies of superior quality raw materials and exclusive collaboration with designers Sireneco—Patenting the most innovative products and adopting use-licenses for installed components	Relationship management, data protection	4.2.2.4

Using these results a company should follow these steps in order to maximise the opportunities of integrating product design into the supply chain:

- (1) Detail the company’s current resources and capabilities.
- (2) Make a detailed SWOT analysis regarding the company’s current integration.
- (3) Use Table 6 to in order to see what actions can be taken to maximise opportunities and minimise risks.
- (4) Make a cost-benefit analysis on each opportunity, weighting the opportunity against its risks, taking the result from step 1 into consideration.
- (5) Make a detailed plan for each area and create projects, which seek to address each identified opportunity and risk.

- (6) Hold a brainstorming session in order to identify potential new areas or ways in which product design can be integrated into the supply chain.
- (7) Go to step 2.

It is essential the company make this review process of opportunities and risk and integrated part of their business opportunity assessment and risk management process so that the company regularly and routinely analyze whether any new opportunities or risks have appeared in the market which they can exploit.

Reviewing the data holistically, it transpires that the higher the level of integration between product design and the supply chain, the more complex the challenges become. This is resultant from the inextricable linkages between opportunities and challenges of integrating product design and the supply chain, which in the case of this research are representative respectively of the interaction between centripetal and centrifugal forces which companies have to balance. This balance is necessary for maximizing the opportunities of integrating product design and the supply chain (see Figure 4):

Centrifugal forces, i.e. challenges pulling companies away from the achievement of a high degree of integration between product design and the supply chain (pressures against a design centric business (Khan & Creazza, 2009)). The findings (see Tables 4–6) showed that these included (see the tables for more examples):

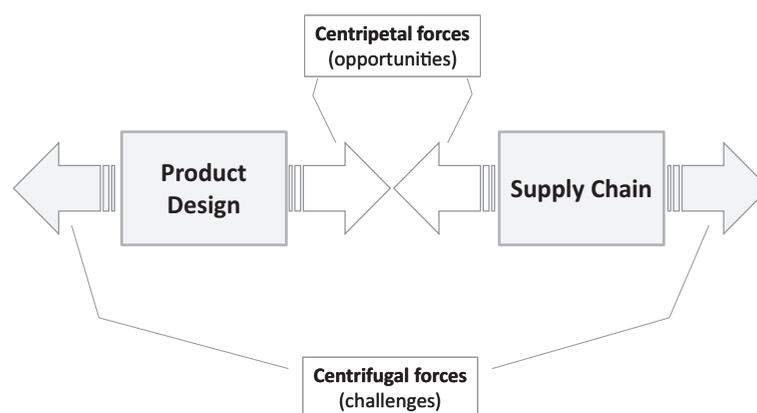
- (1) Poor data and information sharing leading to a poorly responsive supply chain.
- (2) Difficulties to vary the production rhythms and to adapt to new market demands. This is also due to the lack of visibility on the actual market demand and customers' needs.
- (3) Sequential product design process, limited cross-functional communication.

Centripetal forces, i.e. opportunities pushing companies towards the adoption the integration of product design and the supply chain (incentives for a design centric business). The findings (see Tables 4–6) showed that these included (see the tables for more examples):

- (1) Advanced knowledge of technical features for securing purchases of components; reduce purchasing unit costs of components.
- (2) Integrating design for orchestrating the supply chain; training scheme so that designers spend time confronting with the production/supply chain issues they have to deal with.
- (3) The chief executive officer acts as a product design champion.

The research suggests that companies need to leverage the centripetal forces in order to respond to the centrifugal forces to maximise the integration of product design and the supply chain.

Figure 4. Centripetal and centrifugal forces of integrating product design and the supply chain.



Companies must link each opportunity in accordance with the challenge and carefully evaluate the trade-off between the benefits and the effort required, to overcome the challenges of achieving the optimal degree of integration.

Viewing these results within the RBV, it was clear that the companies had different resources and capabilities within product design and supply chain. For some companies a high level of integration resulted in challenges, which could not easily be overcome due to a lack of resources and capabilities to match these. Yet for some of the case companies a high level of integration between product design and the supply chain meant that their resources and capabilities were unique and non-sustainable. As a result this was where the greatest competitive advantage could be created as the more complex a structure the supply chain had, the more difficult it would be for competitors to copy. It was also seen that some companies found it easier to establish certain capabilities than others which meant they could gain some advantages and not others which also meant they could overcome some challenges and not others. To illustrate this we will use Interco as an example in order not to replicate the data-set from Tables 5–7 here. Interco had difficulties with varying the production rhythms and to adapt to new market demands. They were therefore unable to exploit the opportunity of integration to increase “Proficiency of serving customers”. This was because Interco lacked the capabilities necessary to increase their visibility of the actual market demand and customers’ needs. In order to overcome this they would need to build up these competences; for example by hiring new staff, creating a new customer strategy and maybe reevaluating their current Sales and Operations Planning process. Therefore, for Interco to become more successful they would first need to clarify their current resources and capabilities and structure their level of integration occurring to this. Hereafter they could start to look at what opportunities they would like to go after in terms of integration (see Table 5) and which resources and capabilities they would need to build up to avoid challenges (see Table 6).

In conclusion, we recommend that practitioners recognise that the greatest competitive advantage is not necessarily gained by a high level of integration as some companies will not have the capabilities to overcome the challenges involved herein. The greatest competitive advantage is therefore gained by the company wherein the managers have understood to structure, bundle, and leverage their resources and capabilities within product design and supply chain in ways that maximise their contribution towards providing competitive advantage for the company. This means the company, which has understood to balance the centrifugal and centripetal forces in the best possible way for the given market and the given industry and which constantly seeks to adjust and improve upon this as new knowledge is gained.

5. Conclusions and further research

Recent research within supply chain management has focused on supply chain integration. However, the research community has asked for more detailed case studies across industries and countries in order to study this phenomenon in detail. This paper addresses this research gap by analysing how companies can create competitive capabilities through integrating product design with the supply chain. Six case studies were explored to investigate opportunities and challenges of integrating product design into the supply chain. A further contribution revolves around having extrapolated details on opportunities and risks of such integration, across industries and across countries. On a holistic scale, the study presents detailed recommendations for maximizing the benefits of integrating product design into the supply chain. These can be harnessed by academics and practitioners to enable and drive the integration of product design into the supply chain to benefit from increased communication, amplified supply chain visibility, elevated responsiveness as well as the reduction of supply chain risk.

The findings highlight four key opportunities: reduction of production costs, compression of time-to-market, proficiency of serving customers and reduction of supply chain risks. Furthermore, several internal challenges (isolation of functions and mutually inclusive benefits) and external

challenges (integration of upstream tiers, integration of customers, geographical distance and industrial espionage) were identified. The paper also presented practical recommendations to companies on how to overcome the challenges and exploit these opportunities in order to create competitive capabilities through integration of product design and the supply chain.

Viewing the empirical material from a RBV we propose that the key to creating competitive capabilities with integration is achieved when managers understand how to structure, bundle, and leverage their current resources and capabilities within product design and supply chain management in ways that balance the centrifugal and centripetal forces in the best possible way for the given market and the given industry. In other words, the level of integration which will bring about the most competitive advantage for a company will depend on the given product design and supply chain resources as well as the market it operates in (e.g. the centrifugal and centripetal forces). Whether the company is capable of maximizing their potential will depend on the managers' own abilities to balance these different elements.

This paper provides useful insights to both practitioners and researchers. For practitioners detailed recommendations are given on how they can maximise their benefit from integration of product design into the supply chain. Theoretically, these findings are analyzed using the RBV and highlights how integration must be balanced with the company's current resources and capabilities.

While this study renders new insights, it also has limitations. The approach to developing competitive capabilities through integration of product design into the supply chain suggested in this paper should be tested in more companies, in particular from other countries and from different sectors. It could be beneficial to investigate how opportunities and challenges change over time and which parameters influence this. Furthermore, it could be interesting to investigate the similarities and differences of this development in different sectors. Finally, it could be interesting to use such an extended data collection and longitudinal studies to create a detailed framework wherein to view integration in relation to time, market developments, industry and other factors such studies would discover to be relevant.

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Notes

1. In this context, the authors refer to sustainable competitiveness as a way to generate a continued competitive advantage in the marketplace, by integrating product design into the supply chain.
2. The research focused on markets characterised by short product life-cycles exclusively.

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