The impacts of product design changes on supply chain risk: a case study

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DOI:
https://doi.org/10.1108/09600031111118549

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Abstract

Purpose – The main purpose of this paper is to address the impact of product design changes on supply chain risk, and to identify the supply chain risk dimensions in the Chinese special-purpose vehicle (SPV) industry in the context of product design change.

Design/methodology/approach – Case study methodology is adopted to describe the current situation of supply chain risk management in the Chinese SPV industry. Data are mainly collected from in-depth semi-structured interviews, and a cause-effect diagram is used to identify and summarize the internal and external risk dimensions of supply chain risk.

Findings – This study identifies both the internal and external supply chain risk from the perspective of the focal manufacturer in the SPV supply chain. At the level of the external supply chain, customer-required design change normally leads to risk in supply, delivery, and policy. Internally for the manufacturer, the risk dimensions are R&D, production, planning, information, and organization. All of these risk dimensions have their respective causes.

Research limitations/implications – The risk identification of product design change in this paper is only meant to lay a foundation; further case studies should focus on the best practices and approaches of risk management and extend them to other industries.

Practical implications – The current identification of the risk dimensions and their respective causes will help both practitioners and researchers to better understand supply chain risk in the context of product design change. The identified risk dimensions and cause-effect diagram provide practitioners with a risk framework and useful tools to recognize and identify their potential supply chain risks.

Originality/value – This paper shows the 'big picture' of supply chain risk from product design changes in the Chinese SPV industry.

Key words product design, risk identification, risk management, supply chain management, Special-Purpose Vehicle (SPV)

Paper type Case Study

Introduction

Supply chain risk management has emerged as an important source of competitive advantage and an effective method of reducing vulnerability in a supply chain. Along with the fast growing trends of globalization and outsourcing (Kremic, et al., 2006), and the increasing pace of offshore manufacturing (Kumar, et al., 2009) in developing countries such as China, India, and Brazil; the field of supply chain risk has attracted more and more attention from both practitioners and researchers. There are broad literature concerning on risk issues in supply chain, particularly in a global supply chain (Harland, et al., 2003; Barry, 2004; Christopher and Lee, 2004; Manuj and Mentzer, 2008), risk of outsourcing (Lonsdale, 1999; Kremic, et al., 2006; Tsai, et al., 2008), and risk of offshore manufacturing (Warburton and Stratton, 2002).

There are different types of supply chains matching different types of products (Fisher, 1997). A most interesting and emerging issue is that product design is not only a value adding activity (Porter, 1985), but also a potential source of differentiation from competitors (Walsh, et al., 1988). However, the impact of product design on supply chain has largely been ignored (Khan, et al., 2008; Khan and Creazza, 2009). Likewise, the impact of product design change on supply chain risk has also been ignored. Especially in fast-changing markets in which customer requirements change very quickly, supply chain managers need not only to concentrate on product design, but also to devote time into managing risks arising from quick responses to customers' changing requirements. However, empirical studies of the impact of product design change on supply chain risk are still scarce, especially in the Special Purpose Vehicle (SPV) industry.

SPV is a vehicle incorporating a special chassis and designed to meet specialized requirements; examples include watering truck, sanitation truck, oil tank truck, aerial working truck, loading crane truck, firetruck, garbage truck, bulk cement truck, demolition truck, and so on. The Chinese SPV industry has developed very quickly in the last decade. According to statistics from the SPV Branch of the China Association of Automotive Manufacturers (CAAM SPV Branch, 2010), the total annual production in 2000 was 0.18 million SPVs, which comprised 26.94% of total truck production. The total annual production in 2009 increased to 1.65 million, which reached 55.68% of total truck production. Other developed countries such as the United States, Japan, and EU countries have experienced similar rates of development in the SPV industry.

When the open-market strategy launched in the 1980s, the Chinese SPV industry has quickly become involved in a wave of globalization and outsourcing. However, it is still a developing industry in China, and a number of risks have emerged due to the increasing number of global customers outsourcing their production activities to China. Furthermore, customers frequently or urgently require changes to their product designs even after their orders have been put into production by the SPV manufacturer, which makes the product structure more complex. As a complex product as the passage car is, the product complexity affects the business unit profitability (Closs, et. al., 2008). As a result, Chinese SPV manufacturers, as suppliers in such a global supply chain, find that they are continuously struggling with *supply shortages*, *unstable production*, *delivery delay*, and even the *disruption of the entire supply chain*. Meanwhile, 30% customers cannot have their product requirements satisfied on time (CAAM SPV Branch, 2010). Within the scenario of product design change, the SPV supply chain is very fragile. Hence, the main task of supply chain managers of both Chinese SPV manufacturers and global customers in this scenario is to manage supply chain risks in order to keep the whole supply chain operating smoothly and to build a resilient global supply chain.

In light of these gaps, this paper conducts an empirical study on the Chinese SPV industry, and aims to identify the supply chain risk caused by customer design changes. For the purpose of better understanding the impact of design change on supply chain risks, we focus on the following two specific research questions:

Q1: Why do certain supply chain risks occur following design change requests from customers?

Q2: How do customer design changes affect supply chain risk?

Conceptual research framework

Managing risk requires better understanding of the risks (Hallikas, et al., 2004; Faisal, et al., 2006), and at the heart of supply chain risk management is the activity of identifying the risk (White, 1995; Sinha, et al., 2004; Waters, 2007; Rao and Goldsby, 2009). Thus, this paper focuses on identifying the supply chain risk originating from design change requirements.

Much of the interest in supply chain risk is focused on the issues of supply/purchasing (Zsidisin, et al., 2000; Sinha, et al., 2004; Levary, 2007; Blackhurst, et al., 2008), production/manufacturing (Katayama, et al., 1999; Warburton and Stratton, 2002), planning/information (Finch, 2004; Poba-Nzaou, et al., 2008), and delivery/distribution (Cavinato, 2004; Tsai, et al., 2008). However, there are few papers addressing risk issues from the perspective of product design change, particular in the SPV industry, which motivates this research.

According to Waters (2007), supply chain risk can be separated into three categories: internal risk, risk within the supply chain, and risk in the external environment. The *internal risks* originate directly from inside operations of the company and its management decisions and practices on R&D, plan, production, information (Waters, 2007), and organization structure. The latter two risks are both outside of the company; hence, this paper defines them as *external risk*, which includes risk within the supply chain (both from the customer and supplier (Waters, 2007)), and risk from the macro environment affecting the whole supply chain. Because the SPV industry is substantially affected by government legislation, this paper mainly focuses on the policy risk for external risks.

The conceptual research framework is shown in Figure 1.

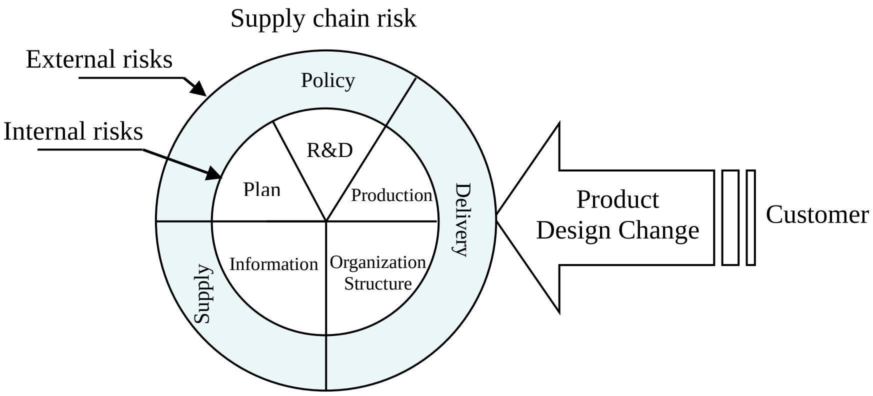


Figure 1. Conceptual research framework

This paper mainly concerns the internal and external supply chain risks due to product design change. The dimensions of internal risk include R&D, production, plan, information, and organization structure. The dimensions of external risk consist of policy, supply, and delivery.

Methodology

1) Case study

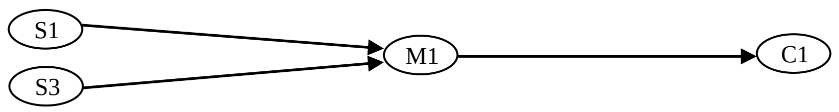
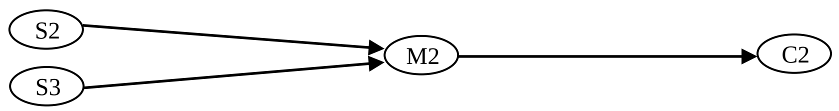
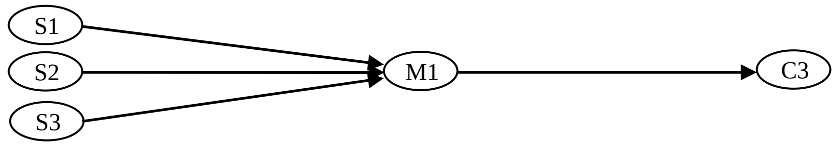
This research aims to obtain a broader perspective on the impact of product design change on supply chain risk in the SPV industry. A case study methodology is adopted in this research to investigate this contemporary (Yin, 2009; Aastrup and Halldórsson, 2009) and complex (Voss, 2002) phenomenon of supply chain risk management in depth, and this method is useful for examining and reflecting upon the emerging nature of the "how" and "why" questions (Yin, 2009) this paper proposed. Furthermore, this study aims to directly observe the risk dimensions in different levels of the supply chain, including supplier, manufacturer, and customer. Hence, a case study is suitable to approach these stages of the supply chain (Seuring, 2008).

To address the research questions and enhance the research results, multiple case studies are conducted in this research, which will produce more robust conclusions (Herriott and

Firestone, 1983) than a single case study; evidence from multiple cases is often considered more compelling than evidence from a single case. Three individual cases are included in this study following the conceptual framework development (see Table. 1). Each individual case study consists of a "whole" case study, and each is carefully chosen and managed in accordance with replication logic (Eisenhardt, 1989), which ensures each single case study in the multiple case study predicts similar results (or named literal replication) (Yin, 2009) and replicates the emergent theory (Eisenhardt, 1989). The replication is a way of establishing external validity of the case study and strengthening the robustness of the original findings (Yin, 2009). However, replication logic should be distinguished from sampling logic, which requires a subset of people from a potential population (Fowler, 2009). Sampling logic is commonly used in surveys but not proper in a case study.

Each of the three case studies defined in this research consists of an entire SPV supply chain, including suppliers, an SPV manufacturer, and customers (Table 1).

Table 1. Multiple-case study

	Supplier	SPV Manufacturer	Customer
Case 1			
	S1 and S3	M1	C1
Case 2			
	S2 and S3	M2	C2
Case 3			
	S1, S2, and S3	M2	C3
Case company overview	***S1: Chassis supplier 1*** S1 is one of the top 3 suppliers providing chassis to both the passenger car company and SPV company. It is a sub-company of a leading group who has well-known R&D	***Manufacturer 1 (M1)*** M1 is approved by the State Development and Reform Commission (SDRC) and belongs to a leading automotive group in North China. M1 has more than 300 types in 10 product series, and owns 11 patents. The key	***Customer 1 (C1) from India*** C1 is the key customer of M1. ***Customer 2 (C2) from Pakistan*** C2 is the key customer of M2.

	capability and sufficient production capacity. S1 is the key supplier to both M1 and M2.	product series include *semi-trailer, dump truck, and tank truck*. M1 has production capacity of annual 20,000 vehicles. 40% of its products are exported to the global market of Far East, Japan, Australia, and North American. Some of the vehicles occupy over 20% of the market share.	***Customer 3 (C3) from Australia*** C2 is a new customer of M1, but with a increased order quantity.
	S2: Chassis supplier 2 S2 is a new merged company between a group company and a local company in Central China. S2 borrowed R&D capability from the group, and has developed its production capacity in recent three years. S2 is the key supplier to M2, Me will seek second supply from S1 when S2 are out of production capacity or delivery delay.	***Manufacturer 2 (M2)*** M2 is approved by SDRC and is located in South China. M2 has developed 9 product series with 276 types in total. Production capacity is around 12,000 vehicles per year. *The leading products include watering truck, sanitation truck, oil tank truck, aerial working truck, and fire-fighting truck.* M2 not only servers the national market in 29 of 31 provinces in China with a high market share (i.e. watering truck series occupies 30% of the total market.), but also successfully exports productions to other countries, mostly to the Far East and North America.	
	S3: Component supplier S3 is a foreign component supplier for both M1 and M2 (for business reason, the country and component name are not shown here). The order lead time normally is 3-4 months.		

2) Data collection

Data are collected through multiple sources of evidence to meet the quality criteria of construct validity (Yin, 2009), or to develop a sufficient operational set of measures and to avoid subjective judgments on data collection. The used data sources include semi-structural interviews, secondary documentations, archival records, and field visits. Using these multiple sources of evidence ensures triangulation logic (Yin, 2009). This method avoids depending upon a single informant, but rather producing more convincing and accurate research results through seeking data from other sources to verify its authenticity by each other.

The data are mainly collected via semi-structural interviews. The interview is regarded as the primary data collection technique for qualitative research (Cooper and Schindler, 2008), and the most valuable and essential source of evidence for a case study method (Yin, 2009). Two types of interviews are conducted during the research in order to explore initial ideas about the research questions (see Table. 2). In-depth interviews with top managers averaged four to six hours in order to extract the interviewees' insights and opinions based on their experiences. The interviews were also recorded and transcribed. Meanwhile, focused interviews, lasting two to three hours, with operational level managers (in the department of purchasing, production, sales, warehousing, and quality, R&D, and logistics operations) both from suppliers, the SPV manufacturer, and customers are conducted to get their operational-level ideas for the research questions. These two types of interview are all designed as open-ended interviews with semi-structured question guidelines (see Table 3) to obtain broader views on the research questions (Blumberg, et al., 2008).

Table 2. Interview list

Supply chain role	Department Participants		People		Average time(hrs/person)	
			In-depth	Focused	In-depth	Focused
Supplier	Chassis supplier S1		3	2	5	3
	Chassis supplier S2		2	2	5	3
	Components supplier S3		2	2	4	2
SPV Manufacturer	Manufacturer M1	CEO	3		6	
		R&D		4		3
		Purchasing		2		3
		Production		3		3
		Sales & Marketing		2		3
		Warehousing		2		2
		Quality		2		2
	Manufacturer M2	CEO	3		6	
		R&D		3		3
		Purchasing		2		3
		Production		3		3
		Sales		2		3
		Logistics (Warehousing)		2		2
		Quality		2		2
Customer	Customer C1		2	2	6	2
	Customer C2		2	2	5	3
	Customer C3		3	2	6	3
Total			20	41	109 hrs	111 hrs
			40		220 hrs	

Several forms of documentation including company information, design drafts, process files, management handbooks, planning materials, and annual reports are collected from official websites and in the field. Archival documents including customer service records, organizational records, lists of names, and other such data are collected after carefully evaluating the accuracy of the records. Field visits are organized to measure and record risk responding behaviors, which is helpful for providing additional information about the topic being studied. For the triangulation of evidence (Yin, 2009), these documents, archival data, and additional information from field visits are used to corroborate the evidence from the interview.

Table 3. Case interview question guideline

Description: This guideline specifies the types of questions we would like to address in the interview. The targeted information of the interview includes:

1. A brief description of the business context and operational process within the interviewee's department.
2. An overview of the possible risks caused by customer design changes.
3. Details of the reasons how a certain risks happened within the supply chain.

General Information

Company: ________________ Department: ________________

Name: ________________ Title: ________________

Position in the company: ______________

Questions about the operational process

1. Please define your department's business function. Does its' operations affected by the customer requirements?
2. Please describe the normally operations processes of your department.
3. Please explain the interfaces between you department and other departments in or out of your company.

Questions about the customer design change

4. What are the most happened customer design changes?
5. Give examples of these changes?
6. How these changes affects the normally operations processes?
7. Give examples of these effects.

Questions about risks caused by the customer design change?

8. What are the most serious results when customer changed the product design?
9. Give examples of the results of customer design change.
10. Does your department/company have any approaches to handle the customer design change?
11. How it works to response to the customer design change?
12. How your department/company communicates and collaborates with other related departments/companies?

Closing questions

13. Would it be possible for us to observe a meeting that involves how your department deals with the customer design change?
14. Would it be possible for us to trace the recent process for dealing with the recent customer design change
15. Thank you!

Reliability of this case study is achieved and enhanced mainly from the development of a case study protocol (Yin, 2009), which helps guide the investigators in this research project in as they carry out the data collection. Case study protocol defined for this case study is in

Table 4.

Table 4. Contents of case study protocol

A. Introduction to the case study and purpose of protocol

1. Case study questions
    a. Q1: Why certain supply chain risks happened following the design changes from the customers?
    b. Q2: How the customer design changes affect the supply chain risks?
2. Theoretical framework for the case study in the SPV industry (see Figure 1).
3. Role of protocol: guiding the case study investigators.

B. Case study design

1. Multiple-case is designed for this case study following the replication logic
2. Each case designed following the conceptual framework
3. Each case (unit of study) covers a whole supply chain, including key suppliers, manufacturer, and key customer.
    a. Manufacturer is the top 3 SPV manufacturer in China, who servers both national and international market.
    b. Customer in each case comes from different country, and it is the key customers of the selected manufacturer.
    c. Suppliers in each case provide key components to the manufacturer, and its operations heavily affected by the customer changes on product design.

C. Data collection procedures

1. Multiple source of evidence
    a. Semi-structured interviews with key informants.
    b. Secondary documentation: company information, design drafts, process files, management handbooks, planning materials, and annual reports.
    c. Archival document: sales records, customer service records, organizational records, lists of names
    d. Field visit (direct observation)
    e. Cross checking is needed for purpose of data validation
2. Semi-structured interview
    a. Two type of interview: in-depth interview with top level managers for 4-6 hours, and focused interview with middle level managers for 2-3 hours.
    b. Preparation for the interview: names of interviewees, roles of the interviewees, contact information, appointment for date and time, room numbers, and necessary accessories including notebooks, pencil or ball pen, and recording pen).
    c. Attempt to secure multiple interviews per field to reduce travelling time.
    d. Attempt to interview informants in their offices rather than interview rooms.
    e. Records all interviews with recording pen after being permitted.
    f. Interview guideline: see Table. 3
3. Preparation prior to field visit
    a. Names of sites (plants) to be visited, including key contact persons
    b. Make initial contact with the companies at the highest level possible.
    c. Make appointment as early as possible.
    d. Find a friendly guide as soon as possible.
    e. Collect sufficient documentary evidence as you can to support verbal information.
    f. Engage as many members of the staff as possible, including secretaries and support people, in general conversation about the companies.

D. Data analysis

1. Follow the conceptual framework to analyze the cases.
2. Pattern matching: compares the empirically pattern (risk dimensions) with the predicted conceptual pattern.
3. Explanation building: develop a rich and full explanation of the cases, and link it to prior related research or theory.
4. Use qualitative data together with quantitative data.
5. Use NVivo software to code and categorize data.

E. Outline of case study report

The following are the primary headings that are established as the key focal points of the case study reports.

1. Introduction: study objective and background.
2. Summary of the case study method
3. The general process mapping of the supply chain.
4. The risks identified within the supply chain.
5. The recommendations of supply chain risk management.
6. Conclusions and discussions of the research results.
7. Implications for theory and practice, future research directions.

F. Case study questions

Detailed questions are listed in the interview guideline (see Table 3).

1. Describe the normally operations processes of your department.
2. Explain the interfaces between you department and other departments in or out of your company.
3. What are the most happened customer design changes?
4. How these changes affects the normally operations processes?
5. What are the most serious results when customer changed the product design?
6. Does your department/company have any approaches to handle the customer design change?
7. How it works to response to the customer design change?

The case study protocol includes an overview of the case study project (research questions and case study design), data collection procedures particularly for interviews and field visits, data analysis and the outline of the case study report, and the case study questions. The main purpose of the protocol is to keep investigators focused on the research topic, even as different researchers conduct different single cases studies. The protocol is used by all investigators on the research team as a guideline for conducting interviews with different informants, which substantially increase the reliability of the case study. Both the questions guideline and protocol are developed earlier in the research process, which help to avoid mismatches and conflicts in the long run.

3) Data analysis

The most difficult and the least developed part of case studies is the data analysis (Yin, 2009). Analytical strategies and techniques are needed to analyze the collected case study evidence.

A conceptual research framework is developed in this study based on a comprehensive literature review. Our case study design and data collection rely on this conceptual framework and its theoretical propositions (Yin, 2009), and analyzing the collected evidence is also based on these propositions. The second strategy is developing a case description. A descriptive framework is helpful for organizing the case study (Yin, 2009). The data collection can be ensured following the descriptive framework, and then the data analysis is easy to be organized within this framework.

Following these two strategies, pattern-matching and explanation building are applied in this research as the major techniques of data analysis. Following pattern-matching logic (Trochim, 1989; Yin, 2009), this study compares the empirical patterns derived from the case evidence with a predicted pattern concluded from the conceptual framework. The pattern coincide will enhance the internal validity (Yin, 2009) of this case study. The other analytical technique is analyzing the case study through building a case explanation. Explanation building is a complex and iterative process (Yin, 2009) that helps in refining the results of case analysis.

To produce a high quality analysis, the study also ensures that the analysis relies on all of the relevant evidence, all major rival interpretations are included in the analysis, the most significant aspect is addressed, and using the investigators' prior, professional knowledge to further the data analysis.

4) Trustworthiness of this study

To ensure the rigor of the qualitative methodology, the study applied nine criteria to evaluate the trustworthiness of the data collection and data analysis following the deployment of Mollenkopf, et al., (2007). These nine criteria include credibility, transferability, dependability, confirmability, integrity (Hirschman, 1986), fit, understanding, generality, and control (Strauss and Corbin, 1998; Mollenkopf, et al., 2007).

Table 5 demonstrates that our data and analyses met these criteria to ensure the quality of this case study research.

Table 5. Trustworthiness of the study and findings

Trustworthiness criteria	Method of addressing criteria in this study
Credibility Extent to which the results appear to be acceptable representations of the data	● Case study report outline is early designed and used by all investigators in the research team ● Two experienced investigators gave input during data collection and interpretation ● Interviewers' initial interpretations are verified with the interviewees simultaneously during the interviews ● **Result:** emergent models are altered and expanded
Transferability Extent to which the findings from one study in one context will apply to other contexts	● Multiple-case study designed following the replication logic ● Multiple source of evidence are used ● **Result:** 1) each individual case study predicts similar results 2) data collected from all informants are represented by the theoretical concepts
Dependability Extent to which the findings are unique to time and place; the stability or consistency of explanations	● Cross reference is organized among the key investigators in our research team, and the findings are double checked by the interviewees ● Case explanation are developed to refine the results ● The interviewees are all experienced managers who understanding recent and past risk events well. ● **Result:** explanation consistency is endured across all the participants
Confirmability Extent to which interpretations are the result of the participants and the phenomenon as opposed to researcher biases	● Documents, records, and summary of preliminary findings are independently reviewed by the key investigators, and key managers who responsible for the evidences. ● **Results:** interpretations are refined and widen
Integrity Extent to which interpretations are influenced by misinformation or evasions by participants	● The interviews are friendly and anonymous to encourage the interviewees to deeply express their personal opinions. ● The interviews are professional, and all the interviewers are well-trained before and experienced in conducting interview. ● **Result:** researchers never believed that participants were trying to evade the issues being discussed
Fit Extent to which findings fit with the substantive area under investigation	● It is addressed through building credibility, dependability, and confirmability in the research project ● **Result:** concepts are more deeply described, and theoretical integration are made more fluid and less linear, which captures the complexities of supply chain risks explored in the collected data
Understanding Extent to which participants by into results as possible representations of their worlds	● Interviewees are asked during the interviews to confirm the accuracy of the interviewers initial interpretations, then made necessary changes ● **Result:** both investigators and participants are better understanding of each other and the interpretations, and subsequent findings
Generality Extent to which findings discover multiple aspects of the phenomenon	● Interviews are lasted sufficient length (5-6 hrs for in-depth interviews, 2-3 hrs for focused interview). ● Semi-structured interviews are open-ended to attract broadly and in-depth insights from the interviewees. ● **Result:** successfully captured multiple perspectives of the phenomenon
Control Extent to which organizations can influence aspects of the	● The risk dimensions within the conceptual framework are business units under control by the interviewee both in the top management

theory	level and operational level. ● **Result:** interviewees are involved in and can influence risk management in their position

* Criteria are adapted from Flint et al. (2002, p. 106), Flint and Mentzer (2000, p. 23), and Mollenkopf, et al., (2007, p. 576).

Findings

1) General supply chain process mapping

The processes from order receiving to delivery are briefly summarized and mapped in Figure 2. The double dotted line shows the specific processes needed to handle the customer requirements with product design change, while the single dotted lines show the normal process. According to the case studies, the potential risks might occur in several stages marked with a pointed star (see Figure 2).

Normally, when the company receives an order from the customer, the sales department signs the contract after estimating the delivery date with the production department. After that, the sales department transfers the sales order into a production order and sends it to the production department to create the production plan. Once the production plan is completed, it is shared with the departments of purchasing, production, R&D, and quality. Based on the production information, R&D works on the design blueprint and process deployment, which is sent to the production department to guide the actual production processes for the SPV.

At the same time, R&D transfers the design into material requirements in the form of a BOM (bill of material), and sends it to the purchasing and warehouse departments. Then the warehouse manager checks the inventory availability of the materials and components, and makes a purchasing requirement for the shortage items.

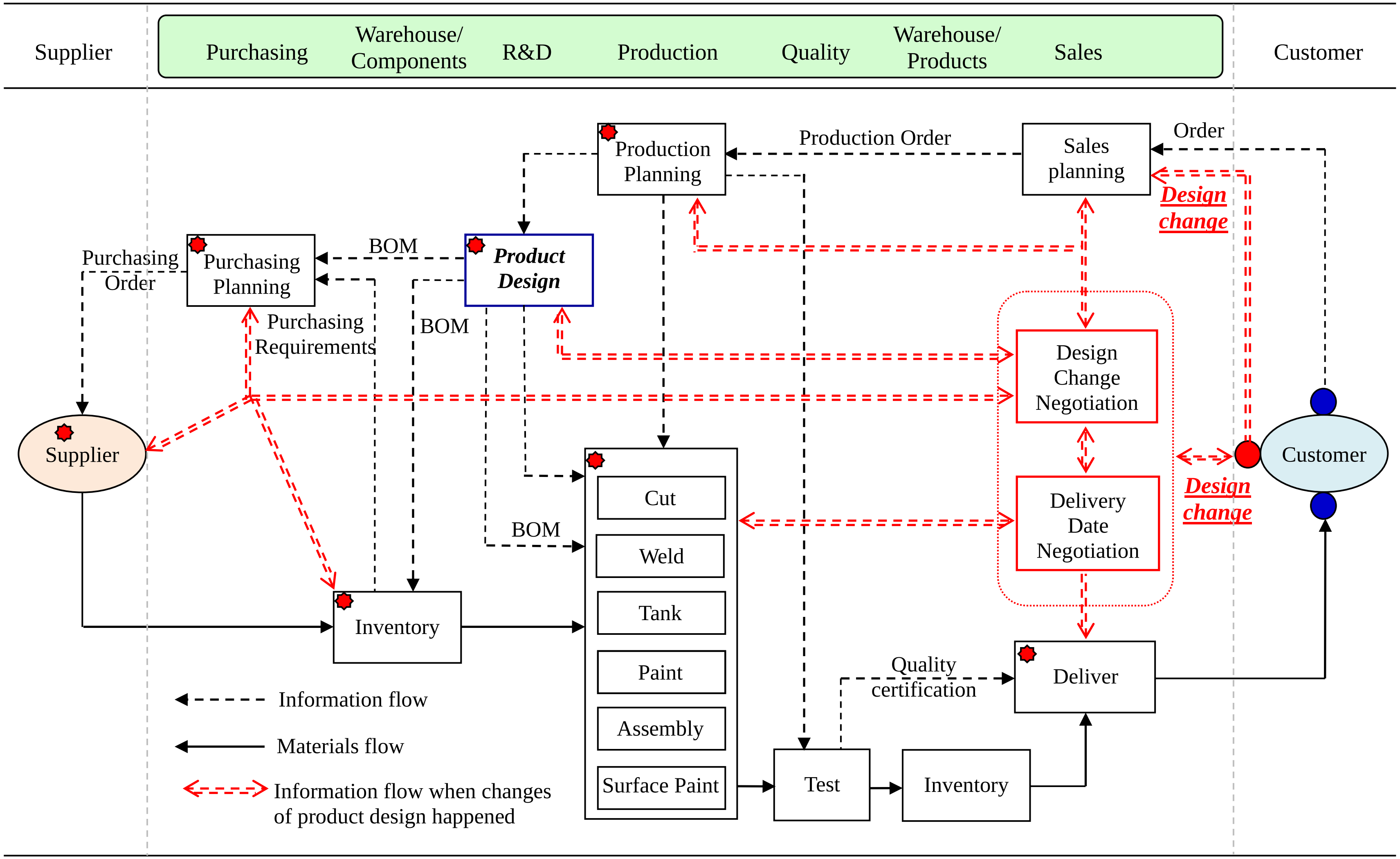


Figure 2. Process mapping of the SPV supply chain

Following these purchasing requirements, the purchasing department places orders with upstream suppliers, who deliver required materials and components to the manufacturer with JIT logic. With the instructions of the production plan and BOM, production processes such as 'cut', 'weld', 'tank', 'paint', 'assemble', and 'surface paint' are completed in the plant. After passing quality tests, all the required documents are prepared before delivering the SPV to the customer, including quality certification, usage instructions, and license plate.

2) Challenges in supply chain operations

The SPV industry is a highly customized-demand market. In such a market, the SPV manufacturer always faces quickly changing customer demands. The order change rate is 10-15%. Most of the demanded changes are related to product design. For example, changing the requirements of the chassis (new brand or new length) and tank volume are the two most common customer requests.

Lack of design capability

When the customer asks for a design change for the ordered SPVs, manufacturers (both M1 and M2) confront several risks in order to satisfy the requirements. From the internal view, the most important bottleneck is lack of design capability, so manufacturers carry risk in its ability to redesign the product to meet customer requirements. Even as an important strategic partner of a 'top 3' automotive company in China that has received great technical support from the relationship, manufacturer M1 itself still lacks in product design and process engineering. Whilst manufacturer M2 has a R&D department in charge of product design, process design, and technology development, but it only has a few engineers in this department. The SPV industry is still a developing industry in China, so these engineers are without enough experience and sufficient training to *redesign* products quickly, not to mention *developing* new products. As a result, it usually takes two to three weeks to respond to customer requirements for product design changes. Furthermore, as the company strategy focuses on seeking new customers and expanding market share, these two manufacturers spend less money on R&D than on sales and marketing. Meanwhile, with more and more changed product designs, it is not easy for the company to establish a stable, unique BOM and product design standards in order to take advantage of standard mass production.

Low level of communication

Redesign risk is also caused by the low level of communication between the R&D and production departments. On one hand, during the design change negotiation stage, communication and collaboration between these two departments is insufficient. Sometimes the R&D department accepts the product change via the sales department without informing the production department to check whether it has the necessary and available production capacity. On the other hand, the redesign process is not like the normal design process in which these two departments work together to make the design and then put it into production. Due to the urgent design change requirements, only the R&D department works on the redesign without requesting immediate feedback from the production department. When the redesigned product blueprint is passed to the assembly line, the workers in the assembly line always complain that the design is impossible to implement with several unreasonable changes. Meanwhile, the engineers in the R&D department claim that the workers are not working hard enough to follow the redesigned product blueprint correctly. The design has to be redone again and again until it can be produced in the plant, costing much time at the design stage.

Especially during the negotiation stage, only sales and R&D become involved in the product change negotiation without involving the production managers. Only after the new product designs are finished do production managers get involved in the delivery date negotiation to produce their estimated date. Poor communication and collaboration extends the total cycle time for design and production, which finally leads to unsatisfied orders and complaints from the customers.

Supply uncertainty

Another major risk is in supply, which is one of the major obstacles of cost control. Product design change results in changing material and component requirements; thus, a shortage of materials, especially of key components, occurs as a vital risk to the manufacturers M1 and M2. For example, the chassis is a key component for an SPV. However, the manufacturer cannot ensure that it can get the customer-specified chassis when the customer changes the product design, even though M1 is a partner enterprise of several famous chassis manufacturers. On one hand, the chassis manufacturers (S1 and S2) normally keep a low level of inventory in order to reduce their own cost pressures; on the other hand, the long physical distance between the chassis manufacturers and the SPV manufacturer causes long supply lead time. As a result, the chassis manufacturers cannot ensure delivery on time. In fact, in such a design change scenario, shortage occurs for both the key components and some high-value components, which both the supplier (S3) and the manufacturer cannot keep a high stock of due to the high pressures of inventory cost and opportunity cost. Meanwhile, when an urgent order for these is placed, the purchasing cost is always very high, and quality cannot always be guaranteed.

Unstable production plan

Production plans are changed frequently to accommodate the customers' changed requirements. Correspondingly, production processes must be interrupted to restart and adjust to the new designs. Hence, the pace of the assembly line is unstable, and it is impossible to set up a stable standard production process, which is one of the company strategies for cost reduction through standardized processes. There are a number of experienced workers in the assembly line, but there are still not enough to make sure the newly emerged company can quickly and effectively satisfy its customers, especially with their changed design requirements. These lead to higher production costs with more setup costs and more labor costs on overtime work. Furthermore, the production facilities cannot achieve the production flexibility to handle the unstable production pace. The worst consequence is quality issues. Manufacturer M2 brings in advanced inspection equipment from overseas, which allows the company to compete with strong completed inspection methods and helps to achieve final product quality test and quality certification, but it still cannot control and improve the quality during production.

In order to retain customers when they put forward design change requirements, both M1 and M2 have to change the production plans, especially for its major customers. Without the help of advanced scheduling and planning software and applications (such as ERP/MRP (Enterprise Resource Planning/Material Resource Planning), APS (Advanced Planning and Scheduling)), the production plans are usually adjusted manually, which cannot ensure an optimized result. Thus, the company has to change its production plans repeatedly during production. It takes a long time to prove the changed plan, which sometimes delays the order delivery.

Delivery delay

For the changed design, urgent delivery dates and delayed delivery occur frequently, especially for overseas customers because shipping has a stable and fixed schedule. When the company cannot catch the planned shipping date, it has to book a new shipping date, translating into a longer delivery time and higher transportation cost, and more transportation costs for urgent delivery. In addition, even for national customers, with the unstable production planning and the less flexible production system, it cannot always meet the customer's timely delivery requirements.

Immature regulation and policy

Because of the immature and un-comprehensive industry regulation and policy system, M1 and M2 always have to explain the reasons why it cannot make the design changes that are against regulations. Especially for global customers, they have to spend much time helping them understand the policies and regulations of the Chinese SPV industry. Furthermore, poor language and communication skills lead to misunderstandings and a mismatch of expectations, which extend the negotiation time for the product design agreement.

The different environmental standards in China and Europe also make negotiation more difficult. Customers from Europe and North American are more concerned about environmental issues, whilst manufacturers in China focus more on production costs and profit.

Discussions

According to the empirical case study and following the conceptual framework, the findings reveal that the supply chain risks originate from two dimensions in the context of product design change, which are external (supply, policy, and delivery) and internal (R&D, production, plan, information, and organization). These risks are critical problems faced by the SPV manufacturer under the scenario of product design change. The risks and their correspondent causes are summarized into a cause-effect diagram (see Figure 3), or described as a fishbone diagram, or Ishikawa diagram (Ishikawa, 1985), which is helpful in showing the relationships as a set of fish bones between risks and their respective causes.

Internal risk dimensions

The internal and external risks compose the supply chain risk. From the ***internal*** view of the SPV manufacturer, the design changes lead to risks in R&D, production, planning, information, and organization structure.

1) R&D risk

R&D risk is the inability to quickly redesign the product to satisfy customers' requirements for design change. Following the requirements for design change, the R&D department should quickly redesign the truck. However, due to the lack of experienced engineers, low-level design standardization, long design cycle time (usually caused by the former two factors), low-level technical innovation, misunderstandings and mismatched expectations usually caused by language and communication problems (Handfield and McCormack, 2005), and a lack of advanced design logic, the R&D risk becomes the primary dimension of the supply chain risk.

Without the application of design for manufacturing (Yim and Rosen, 2008) and concurrent engineering (Anumba, et al., 2002), there is less communications and collaboration between the R&D and production departments, which cannot ensure the changed design is manufacturable in the assembly line. Losing the customer is one of the potential risks because the SPV manufacturer cannot meet the customer's design change or cannot complete the redesign within the time window.

Product design has an important role in the efficient and effective operation of a supply chain (Khan, et al., 2008), particularly from the perspective of supplier involvement (Zsidisin and Smith, 2005). The results of this study show that design change obviously plays a more vital and direct role on supply chain risk from the perspective of R&D; this leads to the SPV manufacturer always stressing *product redesign*, and never mentioning *new product development*.

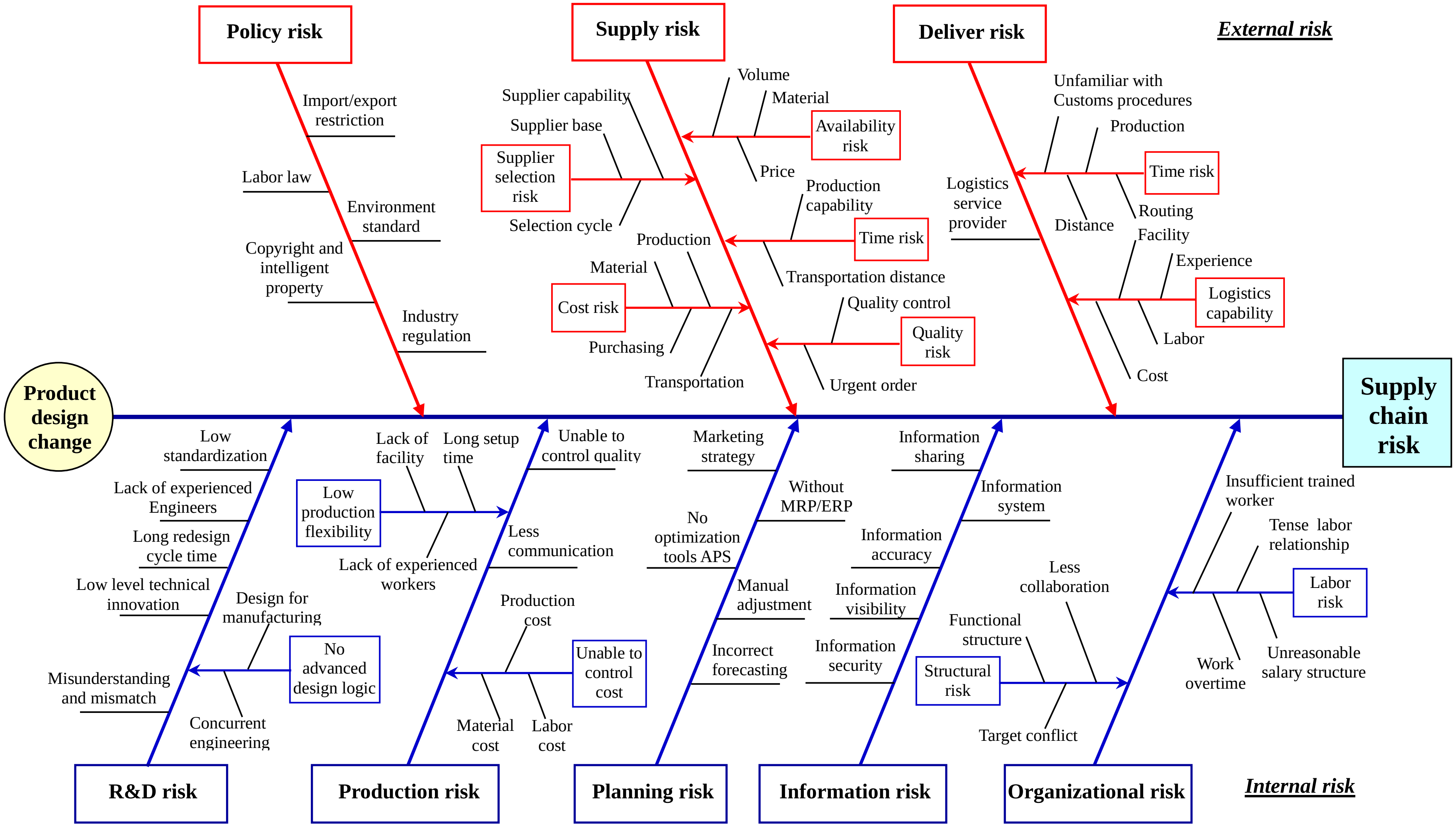


Figure 3. Cause effect diagram of supply chain risk in the context of product design change

2) Production risk

Production risk is the inability to effectively and efficiently produce the products with customers' changed design. This is another important risk to consider when confronting design change. For the SPV industry, production follows a build-to-order (BTO) system (Holweg and Pil, 2001), which means the production pace is affected significantly by the uncertainties arising from customer orders. In particular, the requirements of design change enlarge these uncertainties, which are the critical factors affecting supply chain risk.

Following a changed product design, the SPV manufacturer has to reorganize the necessary resources to complete the customer order. Nevertheless, due to low production flexibility, inability to control quality and cost (material cost, production cost, and labor cost), and less communication with R&D, production risk is one of the major internal dimensions of supply chain risk. The low production flexibility (Upton, 1994) is the result of lacking production facilities and inexperienced workers, and long setup time.

The production risk faced by the SPV manufacturer means high production cost, long production time, and unstable production pace. The high production cost mainly comes from the material waste. For example, an inexperienced worker might cut the steel plate without optimized usage just in order to catch the deadline of the urgent order with a changed design. This always leads to significant waste of the raw materials. Meanwhile, labor costs also cannot be controlled within a reasonable budget, because overtime work is always required to meet the changed design and production plans.

3) Planning risk

The risk dimension related to both R&D and production is planning. ***Planning risk*** is the inability to maintain stable and consistent production planning and scheduling. The Planning risk mainly comes from a customer-oriented market strategy. In order to retain its customers and increase its market share, the SPV manufacturer tries its best to satisfy its customers. Consequently, when the customers require changes in the product design, the SPV manufacturer always accepts those changes and changes its own production plan and reschedules the production activities to meet the customers' demands, which causes chaos and instability for both the planning and production processes.

However, most of the SPV manufacturers did not start using an ERP system to support its planning, due to concerns about the potential risks of implementing an ERP (Poba-Nzaou, et al., 2008), such as cost overruns, user dissatisfaction, and user resistant to change. Without the help of necessary software (such as ERP/MRP) and optimization tools (such as APS), the planners and production managers normally adjust the planned production sequences and scheduled processes manually. Additionally, with the unstable nature of the SPV industry, which is mainly due to the frequently changing product design and urgent delivery time, it is difficult to improve forecasting to match the actual demand (Chopra and Sodhi, 2004) and to support the stability of the planning and scheduling. Furthermore, frequently changing plans lead to an unstable production pace.

4) Information risk

From the perspective of information, there exists an ***information risk*** within the SPV manufacturer, and this also occurs across the whole supply chain (Faisal, et al., 2007). Information risk is the inability to share information among different supply chain roles and make it visible, accurate, and secure across the whole supply chain. Some of the key information, such as BOM and the design, is shared throughout the company, but as (through changes) they frequently are in a state of flux, information accuracy and security cannot be guaranteed, not to mention the visibility of some information, especially the inventory records. These uncertainties affect the accuracy not only of the planning but also of the re-planning (Christopher and Lee 2004). Both the Chinese SPV industry as a whole and SPV manufacturers in China are still in a developmental stage, with limited investment on information systems. All of these cause information risks, which restrict the further development of the SPV manufacturer, especially in the global supply chain.

The information risk not only lies within the company, but also exists in the SPV supply chain (Spekman and Davis, 2004). In the Chinese SPV industry, there is almost no information sharing through the entire supply chain. The reason is that there is less coordination and collaboration among roles in the supply chain. As a result, high transactional cost (Lewis and Talalayevsky, 2004), other unnecessary costs, and chaotic behavior (Childerhouse, et al., 2003) arise when the information cannot be effectively and efficiently communicated and shared through the supply chain and the SPV manufacturer internally.

5) Organizational risk

Organizational risk is the inability of the SPV manufacturer to adjust its organization structure and operational processes to match the dynamic characteristics of customer demand (Aron and Singh, 2005); it includes structural and labor related risks. Centralized, bureaucratic and vertically integrated structures might affect the product development and production processes regarding the time perspective (Shub and Stonebraker, 2009). Within the Chinese SPV industry, most of the SPV manufacturer's organization structure is still functionally based, which leads to a lack of flexibility in responding quickly to fast changing demand. In addition, where departments do not share common goals, and conflicts result when an urgent order is placed. For example, a sale always tries to retain the customer, while the production department focuses more on its cost and productivity. Communication and collaboration are weak amongst these departments. As discussed above, the R&D department cannot collaborate closely with the production department to redesign the product, and sales does not negotiate with the R&D and production departments to make sure the changed design is acceptable. Obviously, organizational risk is closely related with production and planning risk.

Organizational risk occurs along with low efficiency and high cost; the fundamental reason is labor related risks, which have emerged as key risks in global supply chains (Jiang, et al., 2009). With changed designs and unstable production plans, overtime becomes a big burden for the workers, particularly due to an unreasonable salary structure. Furthermore, it forms a tense labor-employer relationship within the company.

Additionally, most of the workers are without sufficient training and experience, which directly affects the effective and efficient operations of the SPV manufacturer, and ultimately the entire supply chain. In fact, lack of skilled and experienced labor is a significant consideration for outsourcing strategies (Graf and Mudambi, 2005). The literature suggests that extensive training is helpful for developing production skills (Gunasekaran, et al., 1994), particularly process engineering skills and technologies, and to help develop employee careers (Shub and Stonebraker, 2009). Meanwhile, training cost and time (Markides and Berg, 1988) must be taken into consideration as part of organizational risk.

External risk dimensions

In addition to these internal risks, there are many ***external*** risks that the SPV manufacturer must acknowledge and overcome. From the external view, the change of the product design has huge impacts on supply and delivery. In addition, the policy risk affects the operation of the whole supply chain.

1) Supply risk

Supply risk occurs when the supplier cannot meet the SPV manufacturer's requirements, such as urgent delivery, material changes, and size changes, which are generated from the final customer's requirements for design change. Supply risk is the inability to guarantee the supply availability, timeliness, cost and quality. Supply risk has been widely studied (Zsidisin, et al., 2000; Harland, et al., 2003; Zsidisin, 2003; Zsidisin, et al., 2004; Ellegaard, 2008) in various business contexts; this paper focus on the factors of availability, time, cost, quality, and supplier selection of the supply risk. The findings show that these are the prevalent risks occurring in the context of design change. *Availability risk* is normally caused by shortage of required materials/components, unsatisfied volume, and unacceptable new price quotations. Due to the long delivery distance and supplier's production capability problems, *time risk* is one of the major risks considered by both the supplier and the SPV manufacturer. Meanwhile, *cost risk*, related to material cost, production cost, purchasing cost, and transportation cost, is another major risk which should be recognized. Finally, *quality risk* is directly associated with the urgent order changes; if the supplier is rushing to satisfy the SPV manufacturer's requirements, the supplier might not have sufficient labor to control quality during busier seasons.

When the SPV manufacturer feels too many pressures from these risks, selection of a new supplier is an option. New supplier selection normally applies to component suppliers, but not to key component suppliers like the chassis supplier. However, it also causes supplier selection risk. The reasons are reduction of supply base, long selection cycle time, and lack of suitable suppliers with sufficient production capability. In particular, size reduction of the supply base (Christopher and Lee, 2004) is the prevalent strategy in the Chinese SPV industry, which helps companies to control their costs. Furthermore, supplier-customer relationships and trust (Spekman and Davis, 2004) issues also should be considered during the selection, which is very important to long-term collaboration. However, the SPV manufactures ignore these correspondent long-term risks when they face immediate design changes.

2) Delivery risk

Downstream along the supply chain, the SPV manufacturer confronts ***delivery risk*** which is the inability to deliver on time and to guarantee the logistics capability. In order to meet the guaranteed delivery date, the production time, customs processing time, vehicle routing (Lee and Ueng, 1999; Giaglis, et al., 2004), and long distances (Levy, 1995) should be considered to handle the potential time risk. In particular, the long distances for overseas customers lead to long delivery times and extra transportation costs. Furthermore, long distances reduce logistics flexibility and affect the performance of logistics, and therefore reduce the positive effects of outsourcing to China, such as cost savings (Fredriksson and Jonsson, 2009).

In addition, the newly emerged SPV manufacturers in China are marked normally by a lack of logistics facilities such as special transportation trucks, enough warehousing space and experienced labor, and the manufacturers have made insufficient investments on these facilities and on training. Most of the SPV manufactures outsource their logistics and customs business to the logistics service providers. Their relationships with these suppliers and providers' capabilities often lead to potential delivery risk especially with an urgent service order. Occasionally, disaster risk (Zsidisin, et al., 2000; Tang, 2006) is another necessary consideration for overseas delivery.

3) Policy risk

Another external risk for the SPV manufacturer is ***policy risk***. Policy risk is the uncertainty associated with industry regulation (Prasad and Sounderpandian, 2003), environmental standards (Handfield and McCormack, 2005), labor law, copyright and intellectual property rights (Song, et al., 2007), and import/export restrictions, which differ from that of the customer's country.

For intellectual property (IP) rights, protection and legal systems in China are less mature than those in Western countries (Song, et al., 2007), and not only the customers, but also the SPV manufacturers should put more focus on IP and copyright issues to avoid the potential risks, such as copying risk, of using the same product design to satisfy another customer.

In general, customers from Europe and North American normally have higher standards (Handfield and McCormack, 2005) than those prevalent in the Far East, and both are different from the standards in China. Sometimes the SPV manufacturer can meet customer requirements, and sometimes it cannot. Therefore, the SPV manufacturers have to maintain balance between competing requirements on design change. Furthermore, more time is spent on explanation and negotiation because of the policy differences. In addition, the stability of the Chinese economy and currency is another vital area that could cause supply chain risk.

For the SPV industry, both internal and external risks should be recognized to avoid the disastrous effects disruptions can have in an SPV supply chain. In fact, success for companies in the context of product design change, both for manufacturers and those in other supply chain roles like suppliers and customers, will come to those who can best identify and manage the various risks that exist internally and externally to the organization (Zolkos, 2003).

Conclusion

Theoretical contribution

Product design plays an important role in the supply chain both on the strategic and operational levels; the most interesting aspect this study has shown is that the requirements of design change have substantial impacts on the supply chain risks in several dimensions, which directly affect the vulnerability and resilience of the whole supply chain. The impacts of product design and product complexity separately on supply chain risk and business unit profitability are discuss in early literature, but the dynamics of product design - design changes this paper has studied is neglected. This paper addresses this gap by identifying the risk dimensions and its causes when customer requesting changes on the product design.

The dynamics of product design have significant impacts on the operations of the whole supply chain, including R&D, production, planning, information, organizational structure, supply, delivery, and policy. These identified risk dimensions are helpful to future researchers to better understand the supply chain risks originated from the product design changes, and the constructed conceptual framework which is verified via our empirical case study in this paper is also helpful to the academia further researches on supply chain risk.

The conceptual framework and the cause-effect diagram this paper has adopted are believed to be a useful framework and tool for risk identification and analysis in supply chain risk management.

Management implications

The supply chain risks summarized in this paper will help both Chinese SPV manufacturers and their suppliers have a better understanding of supply chain risk and identify risks when facing great pressures from customers changing the product design. The identified risk dimensions and its causes show the possible fields and directions for both the SPV manufactures and suppliers to mitigate the potential supply chain risk when customer request changes on the product design.

In addition, it will also be helpful for SPV customers to control supply chain risks when they consider their outsourcing and off-shoring strategy, especially when they request changes on product design. Moreover, the results of this paper help suppliers take customers' design changes into consideration when they optimizing the inventory level and making trade-off decisions on cost and delivery time. Furthermore, it motivates the supplies enhance the long term collaborations with SPV manufacturers in particular on information sharing. The identified risk dimensions should served as the collaboration points not only between suppliers and manufacturers, but also manufacturers and customers.

The conceptual framework and the cause-effect diagram also should be served as practical tools helping managers to identify and analyze supply chain risks in the context of product design change.

Future research

This paper qualitatively identified the risk dimensions and its causes within the context of product design change. Future research should qualitatively explore whether there are more dimensions and causes and quantitatively explore how strong the impacts of product design changes on supply chain risk are.

This research uses the Chinese SPV industry as a case study to identify possible supply chain risks particularly within the context of product design change. Further case studies should be conducted to summarize a more comprehensive framework of supply chain risk dimensions. For the developing Chinese SPV industry, identification of these risk dimensions is only a start. Risk management, including strategies, tools and approaches, should attract more attention from both researchers and practitioners.

More cases should be studied in the future in order to identify best practices to reduce and manage supply chain risks when facing design changes and to set up benchmarks for the SPV industry. Furthermore, the knowledge, theory, and best practices also should be extended and applied to other industries to improve the supply chain performance of risk management.

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