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Multi-Tier Supply Chain Risk Management: Practices and Perspectives

An Empirical Enquiry into the Automotive and Commercial Aerospace Industries

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With contribution of:
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Preface

In mid 2012, the EBS Business School's Institute for Supply Chain Management – Procurement and Logistics (ISCM) and d-fine GmbH formed a collaborative research team in order to gather new insights into the increasingly apparent challenges in multi-tier supply chain risk management in the automotive and commercial aerospace industries. The team's ultimate goal was to promote a constructive, solution-driven dialogue between academic researchers, consultants and practitioners in supply chain risk management. Intended as a starting point for dialogue, this study outlines the research results achieved so far. Contributors, representing the academic and the private sector, provided the institutional collaboration and expertise needed to tackle this complex topic:

- ISCM provided overall project management and were responsible for the data collection and analytical execution of this report.
- d-fine GmbH initiated the collaboration, sponsored the study and provided substantial input drawing on its vast experience of industrial risk management practices.

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Executive Summary

The globalization of markets is at hand (Levitt, 1983). Within this context, the biggest risks to a company are not restricted to disruption or glitches within the organisation. Instead, a company's ability to perform depends strongly on its upstream supply chain partners. Thus, firms should not only seek opportunities to enhance competitiveness through internal efficiency improvements, they should also focus on their upstream supply chain risks and opportunities (Kajüter, 2003). Over the last two years, companies have increasingly witnessed and/or been affected by external upheavals that have led to widespread supply chain disruptions. Many parts of the globe continue to witness unprecedented social and political unrest, natural catastrophes, force majeur and currency instability. Thus, supply chain risk management has become a more critical process for firms to safeguard their long-term success.

Our motivation in researching supply chain risk management in the automotive and aerospace industries is driven by two factors, namely, the observed research gap in academia and the current operational business needs in the knowledge exchange on this topic in practice. The purpose of this study is to analyse the status quo of supply chain risk management in the automotive and commercial aerospace industries. We do so by comparing and contrasting supply chain risk management practices across multiple levels covering Original Equipment Manufacturers (OEMs), first-tier suppliers and second-tier suppliers in order to advance solution-driven knowledge and to provide a cross-industry learning opportunity for practitioners.

The guiding research question in our study is **whether and how companies in the automotive and commercial aerospace industries deal with risks and opportunities in their multi-tier supply chains**. We applied a qualitative research approach based on a case study which included in-depth structured interviews with twenty-two managers from procurement and logistics, sales, and risk management functions. Additionally, we reviewed empirical data such as internal documents regarding the key elements and processes of supply chain risk management as shown in Figure 1.

We found strong evidence to support multi-tier supply chain risk management as opposed to single-tier supply chain risk management. Multi-tier visibility and collaboration enables manufacturers to synchronise planning and to coordinate the execution of activities based on information from all relevant direct partners and other stakeholders along the chain. We found that such an approach provides opportuni-

Fig. 1 Key Elements of Supply Chain Risk Management in the Study

ties to efficiently manage supply chain risks and to reduce the impact and likelihood of disruption. Nevertheless, we identified some gaps in corporate practice when it was evaluated according to acclaimed holistic Supply Chain Risk Management approaches. The gaps were as follows:

1. First-Tier vs. Multi-Tier Supply Chain Risk Management: Supplier risk management is often simplified as direct first-tier supplier risk management, which neglects risk interaction and intersection with multi-tier suppliers. This was found to be more common in the automotive industry than in the commercial aerospace industry.

2. Traditional vs. Dynamic Process of Supply Chain Risk Management: Re-evaluation of the residual risk was not fully integrated in the supply chain risk management process in both industries.

3. Qualitative vs. Quantitative Risk Evaluation: Many companies from both industries relied on a qualitative view of risk evaluation without real quantifiable evidence.

4. IT System and Tools vs. "Soft" Corporate Resources in Supply Chain Risk Management: Companies from both industries studied relied heavily on IT systems and tools and considered them as the enablers of supply chain risk management.

Based on the empirical research, we introduced four conceptual models or approaches to assist companies with mitigating multi-tier supply chain risks and seizing potential business opportunities.

- The Three-Circle Model helps managers to identify risks from a multi-tier supply chain partner. This model can be applied in both industries, but it is more applicable for the automotive industry, as we found that in the automotive industry there was a stronger tendency for supply chain risk management to target only the first-tier supplier.

- The Risk Portrait of the Multi-Tier Supply Chain Partner Model increases the risk visibility and comparability of the selected multi-tier supplier. This was relevant to both industries.

- The Multi-Tier Supply Chain Risk Management Circle Model treats the risk management process as a dynamic system. This model concentrates on integrating the re-evaluation of the residual risk in the supply chain risk management. This model can be applied in both studied industries.

- The quantitative approach to assess multi-tier supply chain risk includes five basic steps, namely, prioritisation of supply chain risk by using tools such as Risk Mapping; quantification of the risk impact; modelling joint risk factor dynamics; calculation of the risk probability distribution and aggregation of supply chain risks.

Besides the above-mentioned conceptual models, we claim that in the risk management process an efficient balance across IT systems, leadership and communication system should be obtained. Although for some companies, successfully managing the multi-tier supply chain and its inherent risks can offer a real competitive advantage, and for other companies, multi-tier supply chain risk management has become a prerequisite for success or even survival, we argue that it is corporate strategy, core competencies, corporate resources and the business environment that determines how multi-tier supply chain risk should be managed. Thus, there exists neither a multi-purpose solution nor a quick fix for imitating the best supply chain risk management practice. Only a suitable and robust supply chain management approach enables a company to produce a balanced set of goals that align with the overarching corporate performance goal whilst at the same time mitigating supply chain-related risks that affect their own operations.

1 Research Background

1.1 Motivation

Our motivation for studying supply chain risk management stems from our observations from both academia and business. Globalisation, specialisation (focusing on core competencies) and lean production at the same time provide the automotive and commercial aerospace industries with numerous opportunities and challenges. Companies at all tier levels in these two industries thrive by achieving and sustaining high levels of customer satisfaction and cost advantages. Applying this dual approach to simultaneously attaining cost efficiency and responsiveness makes supply chains more vulnerable to risks such as delays in transportation or production schedules, quality problems from suppliers or force majeure. Hence, effective management of these risks seems to demand an integrated approach towards supply chain information and product flows.

As companies in automotive and commercial aerospace industries become increasingly global in their supply, production and sales footprints, this vulnerability is further revealed. In particular, supply problems can arise from port disturbances, labour strikes, fuel price fluctuations and the general volatility that characterises emerging markets. Risk or disruptions in the product flow may have devastatingly negative consequences both for an individual firm and for the supply chain (Paulsson 2007).

The growing amount of research on supply chain risk and disruptions resulting from natural disasters or human actions, political and economic instability and market dynamics has also indicated that risks and subsequent disruption have become the new norm in supply chain operations, and this requires (pro)active management (Berger et al., 2004; Christopher and Lee, 2004).

In practice, there is a widely held belief among managers that recent years have seen a palpable increase in supply chain risk and disruption. In 2013, a major Japanese automotive OEM recalled nearly four million vehicles worldwide due to safety concerns caused by quality problems originating from their airbag supplier. Similar recalls are almost never caused by the manufacturer's own engineering lapses, but by a deviation in some material or process from a supplier, sub-supplier or sub-sub-supplier (Financial Times, 2013). According to a Swiss Reinsurance Company study, worldwide economic losses from natural disasters in 2010 totalled USD 194 billion (Swiss Re, 2011). Such disasters can damage supply chain infrastructure and significantly impact private sector financial performance: an analysis of fifteen publicly listed multinational companies indicated that operating profits fell by up to thirty-three per cent in the financial quarter following the 2011 earthquake and tsunami in Japan as a result of supply chain disruptions (World Economic Forum, 2012).

As Waters (2007) states, "an interruption to the supply chain can have widespread effects. Shareholder return typically falls by seven to eight per cent on the day that a disruption is announced; operating income falls by forty-two per cent and return on assets is down by thirty-five per cent." Based on a sample of 519 announcements made during 1989–2000, Hendricks and Singhal (2003) find that glitch announcements decrease shareholder value by about eleven per cent. After all, it does not matter where in the supply chain a risk or disruption is caused, what matters is the detriment caused by this risk or disruption.

Business leaders who can exploit the complexity of the entire supply chain to deliver value and also drive business sustainability for both customers and trading partners are increasingly being hunted by boards of directors. According to Gartner's report in 2011, the number of supply chain executives elected as or reporting directly to the Chief Executive Officer (CEO) has increased from thirty per cent in 2005 to sixty-eight per cent in 2010. Thus, the need for agility and a better understanding of the supply network takes precedence in the C-suite of companies (Winter, 2012).

Our motivation for adopting the empirical qualitative research approach was driven by "a shortage of empirical research in the area of supply chain risk management" (Sodhi et al., 2012), and limited empirical research into the risks prevalent in supply chain networks (Harland et al., 2002). Even less empirical research is available on comparisons between supply chain risks across different industries. Such an industry comparison, as is conducted in this study, can provide interesting process and practice benchmarks.

In addition, more qualitative research is needed to better understand the variety of different risks and the processes that allow active prevention and management (Kern et al., 2012). Research methods suitable for capturing the holistic as well as the dynamic behaviour of risk within supply chain networks were found to be clearly lacking (Ghadge et al., 2012). Thus, a multiple case study involving an analysis of not only a firm's direct suppliers (first-tier suppliers), but also its suppliers' suppliers (second-tier suppliers) was conducted. This seemed necessary in order to attain a more holistic picture of the supply chain risk management approaches practiced across the multiple entities in a supply chain (Trkman and McCormack, 2009).

Three primary forces led us to focus on two specific industries in this study:

Firstly, automotive supply chains are highly synchronised and firms in the chain are highly dependent on each other (Mudambi and Helper, 1998). This statement also holds true for supply chains in the commercial aircraft industry (Linz and Rothkopf, 2010). Therefore, they are comparable in

this context. Moreover, both industries are dominated by a limited number of OEMs that each employs an exponentially large number of first-tier and second-tier suppliers. The increasing modularisation of major components of the final product has contributed to this value creation structure in both industries.

Secondly, both industries operate in highly competitive global marketplaces. To capture and maintain market shares, products must meet customer requirements by improving product performance, quality and reliability, which, in turn, require robust and resilient supply chains. Moreover, OEMs in both industries must continuously launch new models or deliver technical improvements of existing models. Thus, they are also relying on their supply chain partners' innovation capabilities.

Thirdly, automotive vehicles must be affordable to a huge and diversified market. As such, the throughput of manufacturing must be extremely high, whilst at the same time it relies on Just-in-Sequence component delivery in order to reduce inventory costs. Although the production rates for the commercial aerospace industry may be lower than those of the automotive industry, its labour productivity, manufacturing methods and customer requirements have similar implications for supply chains. In particular, high component costs require commercial aircraft manufacturers to focus their capital lock-up on their inventory. Moreover, both industries manufacture their products on a made-to-order basis rather than a made-to-stock one.

1.2 Research Purpose and Questions

The purpose of the study is to analyse the current position of supply chain risk management in the above-mentioned industries in an attempt to develop solution-driven knowledge and to progress the cross-industry learning effect on the content and processes of multi-tier supply chain risk management for practitioners in both automotive and commercial aerospace sectors.

Questions raised in this study include:

- What do the empirical results observed in the supply chain risk management of automotive and commercial aerospace industries indicate?
- Which tools do, or should, companies use to identify, assess and mitigate risks in their multi-tier supply chains?
- What is the cross-learning effect between automotive and commercial aerospace industries and among the various firms along the supply chain?
- What is the importance of a holistic perspective for multi-tier supply chain risk management?

1.3 Definitions and Research Scope

Supply chains are composed of entwined sets of interacting entities of nearly unimaginable complexity and sophistication. In both the automotive and commercial aerospace industries, the supply chain is organised according to the tier structure, as shown in Figure 2.

Because of this intrinsic nature, many argue that the term "supply chain" paints rather a simple picture and should therefore be replaced by supply networks or supply and demand networks. Alternative terms refer to a "logistics channel" to emphasise marketing; a "process" to emphasise operations and a "value chain" to emphasise value added (Porter, 1985). However, such differences refer simply to semantics rather than to content.

In the absence of a commonly agreed definition of the term "supply chain," in this study, the supply chain is defined as a) the processes from the supply of initial raw materials to the ultimate consumption of the finished product linking across supplier-user companies; and b) functions within and outside a company that enable the value chain to make products and provide services to the customer (Cox et al., 1995).

According to the Council of Supply Chain Management Professionals (CSCMP), "[supply chain management] encompasses the planning and management of all activities involved in sourcing and procurement, conversion and all logistics management activities." The concept also places emphasis on coordination and collaboration between channel partners, which refers to suppliers, intermediaries, third-party service providers and customers. Guided by this definition, we started our analysis from the position of OEMs and covered their upstream channels including first-tier and second-tier suppliers.

Risk itself can be described as disruption, vulnerability, uncertainty, disaster, peril and hazard (Ghadge et al., 2012). Supply

chain risk can be broadly defined as exposure to an event which causes disruption, thus affecting the efficient management of the supply chain network.

A diverse classification of supply chain risks is available in the literature. Based on the work of Norrman and Jansson (2004), we divided supply chain risk content into six categories, namely, (1.) market risk, (2.) liquidity risk, (3.) volume/capacity/demand risk, (4.) counterparty risk, (5.) operating risk and (6.) risk interrelations.

1. Market risk refers to the possibility of losses caused by adverse movements in market prices. Market risk is derived from sources such as fluctuations in exchange rates, interest rates and prices of commodities or sourced components.

2. Liquidity risk refers to the inability to meet obligations derived from supply chain activities (e.g. payments to suppliers).

3. Volume/capacity/demand risk derives from fluctuations in production and demand levels such as those caused by changes in customer preferences.

4. Counterparty risk arises from the possible non-performance of contractual obligations by counterparties, in particular suppliers or customers.

5. Operating risk denotes the risk of loss resulting from inadequate or failed internal processes, people and systems, or from external events. Examples include inadequate procurement forecasts, production breakdowns and workers' strikes.

6. Risk interrelation refers to interactions between different risks. For instance, outsourcing can mitigate operational risk in an organisation while control over the outsourced processes decreases and thus, counterparty risk increases. In many cases, risk interrelations can also lead to an amplification of the underlying risks and their potential impacts. As an example, consider a company using EUR as its reporting currency that plans to purchase components against the USD. In this context, the impact of rising component prices in USD can be aggravated by an appreciation of USD against EUR.

Supply chain opportunity is defined as an event or situation which could allow a company to leverage a direct or indirect positive impact on achieving the corporate objective. There are two broad categories of supply chain opportunities:

1. Operational opportunities such as supply chain cost optimisation, faster supply chain response time and improvements in customer metrics;

Fig. 2 Tiered Supplier Structure in Both Studied Industries

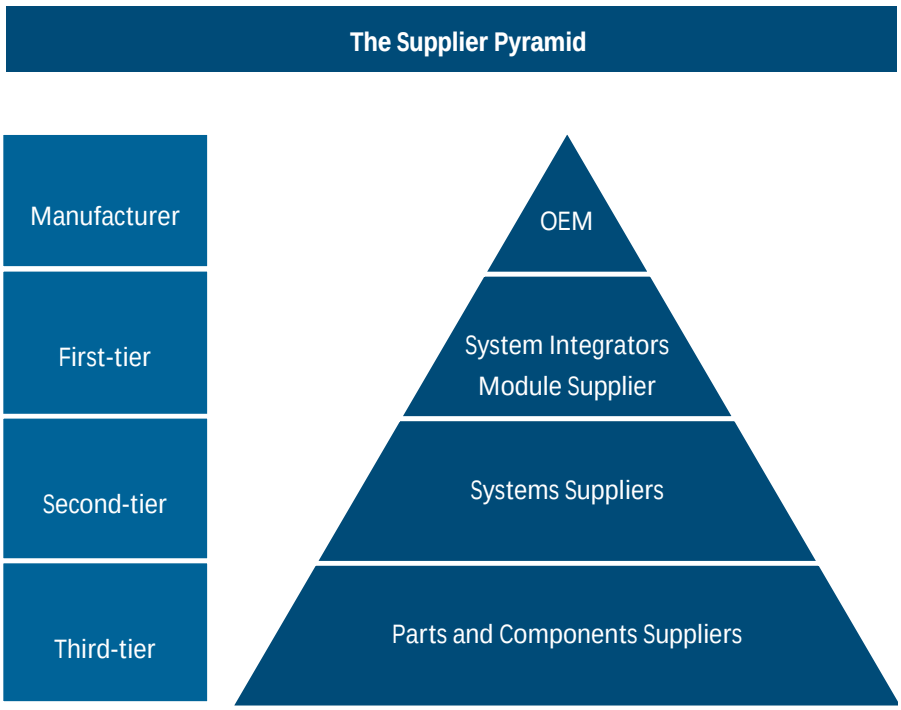


Table 1 Supply Chain Risk Management Strategies: Proactive vs. Reactive

Proactive Risk Management Strategy	Reactive Risk Management Strategy
• Supplier development/management: risk sharing through contract manufacturing, contractual governance, dual/multi-sourcing • Supply chain contracts: developing incentive contracts, mix and volume flexibility contracts for risk mutual benefits, buffer stock • Product/process management: product variety, postponement, product design and delivery management • Supplier relationship: supplier collaboration through improved confidence, cultural adaptation, continuous coordination	• Contingency planning: strategic event management plan, enhanced flexibility in options • Disaster management: robust recovery, rebuilding of supply chain, resource utilisation/ management, scenario analysis for future disruptions • Demand management: operational rerouting, shifting customer demand, dynamic pricing

2.Strategic opportunities such as supplier rationalisation and strategic relationships with suppliers.

After viewing different notions of supply chain risk management, in this study we define the term as "the management of supply chain risk through coordination or collaboration among the supply chain partners so as to ensure profitability and continuity" (Brindley, 2004).

Supply chain risk management strategies are classified in proactive and reactive approaches. Proactive risk management refers to the approach that avoids potential risk events from occurring.

Reactive risk management is to respond to risk events that have already occurred so that consequences can be addressed. One of the reactive risk management strategies that many companies follow is contingency planning. This type of risk response, where there is a defined process or response plan, will limit the impact or duration of the risk event after a risk has occurred. Key proactive and reactive risk mitigating strategies discussed in the literature are shown in Table 1 (Ghadge et al., 2012).

1.4 Research Methodology

The applied research method was inductive and was based on a) a literature review and b) multiple case studies. The literature review was performed via a thorough evaluation of existing research into risk and risk management in other disciplines, such as finance, insurance and engineering, and also in our focal areas of supply chain management and supply chain risk management.

A case study as the primary research method is "an empirical inquiry that investigates a contemporary phenomenon within its real-life context" (Yin, 2003). It is a research strategy which concentrates on perceiving the dynamics present within single settings (Eisenhardt, 1989). From January to July 2013, we conducted in-depth interviews with representatives from the automotive and commercial aerospace industries covering OEMs, first-tier suppliers and second-tier suppliers. We used semi-structured interviews as our primary Data Collection Method to systematically record supply chain risks prevalent in the supply chains and the processes associated with managing these risks (Romeike and Hager, 2009).

After transcribing the interviews, we coded them according to scientific qualitative data analysis techniques (Strauss and Corbin, 1989). The coding provided us with a thematic analysis approach (Guest, 2012) and allowed us to compare and contrast risks and management practices based on their strengths and intensities.

We began our research with the fundamental assumption that supply chain risk management is a social process and as such is affected by a variety of behavioural factors. The structured Interview Guideline contained fifteen questions. These questions were designed to shed light on:

- What are the supply chain risks in each of the case study industries? What are the similarities and differences?
- What are the sources and drivers of supply chain risks?
- In terms of proactivity and/or reactiveness (see Table 1), what is the risk management strategy of the interviewed company?
- What does the supply chain risk management process look like? How do the interviewed companies integrate multi-tier suppliers in order to manage supply chain risks?
- What IT systems and tools are applied for supply chain risk management?
- How do "soft" parameters (e.g. managerial commitment, intra-organisational communication mechanisms, corporate risk culture) play a role in supply chain risk management?

Three analytical angles running through the analysis include industries (automotive and commercial aerospace), tiers (OEM, first-tier supplier, and second-tier supplier) and business functions (procurement and logistics, sales and risk management). These angles are compatible with the design of the Interview Guideline and the selection of the informant. Based on the interview results and other research outcomes, we provided further suggestions and recommendations.

1.5 Interview Participants

From January to July 2013, twenty-two contributors from eight companies participated in our two-hour interviews, held in English. The coverage and distribution of the interviews are illustrated in Table 2.

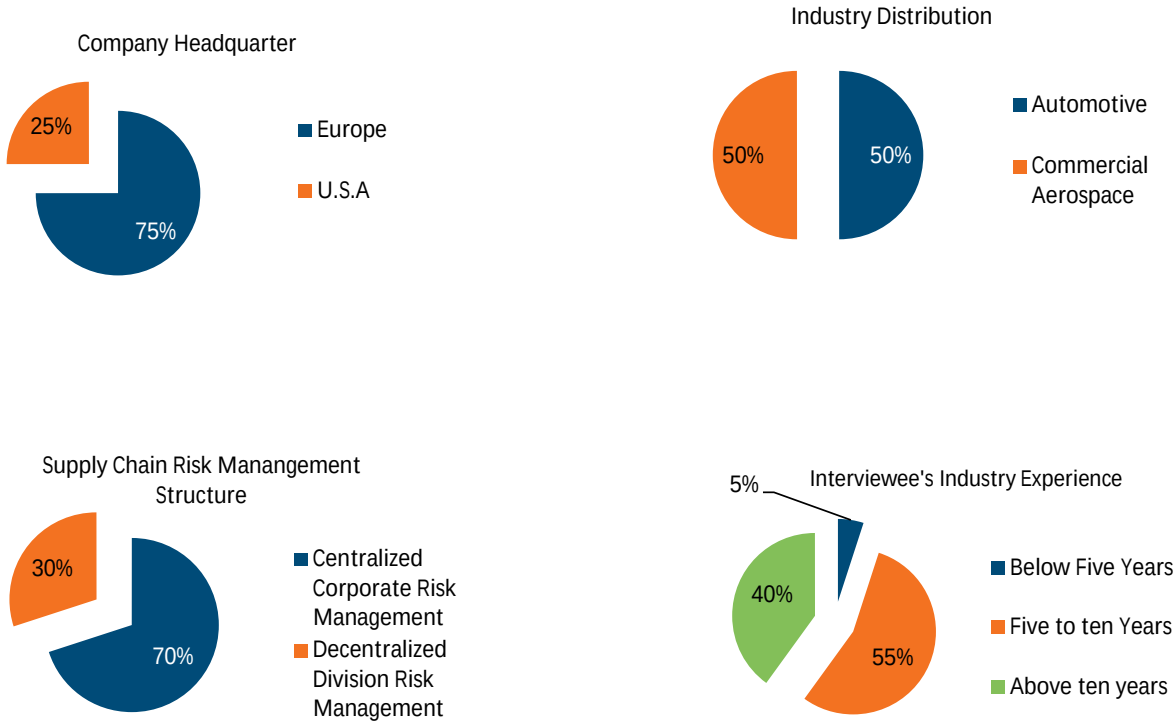
Ninety per cent of all interviews took place in person and the rest were via telephone conference. Seventy-five per cent of the sample companies have European headquarters. The number of interviews was balanced between companies from both industries. About seventy per cent of the interviewed companies have a corporate risk management division with assigned individuals in charge of supply chain risk. For the rest, supply chain risk management is allocated to each division or organisational function, such as production and sourcing, or to a functional area, such as quality management, or to a special taskforce team. Nearly half of our interviewees have industry experience of more than ten years. Seventy per cent of them hold middle or high managerial positions in the corresponding division.

Descriptions of the interviewees and their companies are summarised in Figure 3.

Table 2 Interview Coverage and Distribution of the Study

		Tier		
		OEM	First-Tier Supplier	Second-Tier Supplier
Industry	Automotive Industry	5 Interviews	5 Interviews	2 Interviews
	Commercial Aerospace Industry	2 Interviews	5 Interviews	3 Interviews

Fig. 3 Descriptive Statistics of the Interviewees and Company Headquarters



2 Industry Characteristics

Both automotive and commercial aircraft industries are capital intensive, complex, dynamic and are subject to shortening innovation cycles. However, there are also significant differences between them.

From the production perspective, European automotive assembly plants are sophisticated in their automation, outsourcing and just-in-sequence deliveries. Car producers have accumulated the experience needed to draw up supply strategies that are likely to be enduring, taking into account that any substantial supplier changes during the product life cycle of a car model is costly and organisationally difficult (Aláez-Aller and Longás-García, 2010).

As a result of progressive liberalisation, the passenger airline transportation industry, which is one of the main customer bases for aircraft OEMs, has become inherently unstable. For the last fifty years, the commercial airline industry has been characterised by continued and rapid growth in demand for its services. Yet, this rising demand has produced only marginal profits. The airline industry appears to be cyclical and this inevitably impacts on sustainable growth from year to year (Doganis, 2002). However, in the automotive industry, the growing demand for vehicles, which has been invigorated in recent years by consumers from emerging countries, brings with it increased revenue and profitability.

The typical automobile is made up of approximately twenty thousand detailed parts with about one thousand key components coming together at the point of assembly. Peter Drucker has described the automotive industry as "the industry of industries," because it consumes output from just about every other manufacturing industry (Thomas, 2012). In comparison, an aircraft may comprise of over one million unique parts. The product life cycle of a car is around eight to ten years, whilst an aircraft usually lasts much longer. However, in both industries supplier value creation is organised according to the tier structure. The widening of the pyramid towards its base reflects the growing number of suppliers and the corresponding increased complexity of the relationships between them. At the same time, the tier structure reduces the number of direct relationships between the OEM and its suppliers, which makes the production complexity workable for the OEM.

For both automotive and commercial aircraft OEMs, the external sourcing volume is an important part of the total cost, which is mostly the result of their heavy reliance on external suppliers in the production of systems and component supply. For instance, the sourcing volume of one of the world's leading aircraft OEMs accounts for about two-thirds of its annual sales. In the automotive industry, externally purchased materials account for sixty to seventy per cent of the manufacturing costs of a new car made by the Big Three U.S. automakers (National Academy of Sciences, 1993). The world's leading Japanese car manufacturer sources about seventy to eighty per cent of its manufacturing costs from external suppliers (Carey, 2005). Therefore, companies in both industries are increasingly reliant on their suppliers, thus the company's performance is to a large extent determined by the quality of the underlying supply chain.

3 Supply Chain Risks and their Management: What, Why and How?

3.1 Main Interview Findings

Based on our case studies, we can summarise the following ten phenomena that demonstrate the most striking differences and similarities within and across the two industries studied.

1.The current industrial environment causes cognitive bias[1] according to interview participants who perceive risk differently and thus produce different action plans. In the last two years, companies have been alarmed and/or been affected by devastating events such as the Fukushima disaster or recent volcanic eruptions in Iceland. The interviews confirmed that cognitive bias has an impact on our interviewees from both industries, for example, when dealing with external events.

2.In the automotive industry, with respect to types of supply chain risk, we discovered that the top three risks which absorb the most corporate resources and demand the most managerial involvement are market risk, operating risk and volume/capacity/demand risk. By contrast, in the commercial aerospace industry, besides market risk and operating risk, liquidity risk and risk interrelations are also significant management concerns.

3.Turning attention to the sources/drivers of supply chain risks, our findings showed that the evolving nature of supply chains and business models, such as just-in-time, lean management, single-sourcing, outsourcing and offshoring has led to changing risk distributions, which is common to both industries studied.

4.In terms of interviewees' perceptions of supply chain risks, we found that risky events with straightforward and tangible impacts seem to capture more management attention from both industries than risks with severe but hidden or non-quantifiable impacts.

5.The majority of the interviewed companies follow the traditional four-step supply chain risk management process, namely, risk identification; risk assessment; development of risk mitigation strategies and tools; and execution of risk management capabilities. Re-evaluation of the residual risk[2] is not commonly practiced, although it is considered by most interviewees as being a proactive and recurrent assessment step. We did not find clear a co-relationship between this phenomenon and the industry where the interviewed company operates.

6.Supplier risk management is often simplified as direct first-tier supplier risk management, which neglects risk interaction and intersection from multi-tier suppliers. This was found to be more common in the automotive industry than in the commercial aerospace industry.

7.Two-thirds of our interviewed companies had installed or upgraded supply chain management-related IT systems in the business division or at the corporate level in the last eighteen months. Interview responses showed that the two industries place similar levels of importance on developing IT systems to optimise supply chain risk management.

8.Our findings showed that, when a supplier risk model is in place, it is often built upon modelling historical financial performance and trends as a predictive indicator of future supplier financial performance. Interviewed companies conduct very limited independent risk-based due diligence[3] to verify a supplier's ability to deliver fully against their contract. Two exceptions to this were a first-tier automotive supplier and an aerospace OEM.

9.Above half of the interviewed companies perform rather basic supplier segmentation, generally based on high and low gross margins, short and long lead times, or high and low levels of innovation. Classifying the company's relationship with individual suppliers into modes such as strategic, tactical or transactional is not generally practiced. The nature of the industry itself does not seem to explain this phenomenon. According to our limited data, we could conclude that the more complicated and diverse the supplier base, the greater the likelihood of the company developing a more advanced supplier segmentation regime.

10. Risk communication flows often stay within a single plant or business division. There is a lack of collaborative and integrated risk communication schemes across internal locations and entities. Our interviewees from both industries report this as a commonly occurring barrier.

In Tables 3 and 4, we summarise and group the interview results into six areas of supply risk management which we queried based on our Interview Guideline:

1) source of supply chain risk,
2) risk management strategy (proactive vs. reactive),
3) risk management coverage and depth along the supply chain,
4) risk management process,
5) risk management systems and tools and
6) risk management "soft" parameters: such as resources, culture, commitment of the management, and communication.

1 A cognitive bias is a pattern of deviation in judgement, whereby inferences about other people and situations may be drawn in an illogical fashion (Haselton et al., 2005).
2 We define residual risk as the exposure to loss remaining after other known risks have been countered, factored in or eliminated.
3 Risk-based due diligence refers to the steps companies should take to identify and address actual or potential risks in order to prevent or mitigate adverse impacts associated with their activities or sourcing decisions (OECD, 2013).

Table 3 Main Interview Findings in the Automotive Industry

		Unit of Analysis		
		OEMs	First-Tier Suppliers	Second-Tier Suppliers
Dimensions	1) Source of Supply Chain Risk	• Demand and operating risks due to lean management and outsourcing • Counterparty and regulation risks • Risk of supply chain sustainability[4]	• Operating risk due to on-time delivery and lead time • Market risks especially due to raw material price • Supply chain complexity • Counterparty risk of the suppliers	• Market and demand risks • Operating risk • Counterparty risk of the B2B customer
	2) Risk Management Strategy: Proactive vs. Reactive	• Both proactive and reactive, such as early supplier involvement and supplier collaboration • Long-term perspective on supplier evaluation • Supplier relationship building strategy	• Both proactive and reactive, such as supplier development and contingency planning • Dual sourcing strategy	• Both proactive and reactive • Supply chain cluster management[5] • Supplier development through contract manufacturing
	3) Risk Management Coverage and Depth along the Supply Chain	• Direct coverage only on selected first tier • Downstream to car dealer • Competitive & contractual relationship with first-tier suppliers	• No risk transfer but risk sharing (such as the fluctuation of raw material price) with OEMs • Only first tier but with a certain impact on and indirect monitoring of sub tier	• Upstream only first tier • Monitoring of credit standing of key account customers
	4) Risk Management Process	• Early warning indication (quality & delivery) • Regular evaluation of key suppliers • Lack of sufficient re-evaluation of the residual risk	• Early warning indication (quality & delivery) • Regular evaluation of key suppliers • Long-term agreements with raw material suppliers • Lack of sufficient re-evaluation of the residual risk	• Risk management process at both corporate and division levels • Early warning indication
	5) Risk Management Systems and Tools	• SAP package for supply chain management • Key Performance Indicators (KPIs) to measure quality, on-time delivery and so on • Tools to improve transparency of risk and its management in need	• Enterprise Resource Planning (ERP) • Corporate risk management software (Opture®[6]) • External credit information (Creditreform[7]) • External finance and country risk information (Coface) • Consignment stock management[8] • KPIs	• Standardised and tailored IT systems for data transfer and sharing • Risk management team based on the cluster of suppliers and/or customers
	6) Risk Management "Soft" Parameters: Resources, Culture, Leadership[9], Communication, etc.	• High dependence on IT systems and tools • Special task force/team for risk management • Emphasis less on risk ownership for the individual	• High individual commitment of executives required • Emphasis on site visit and timely communication • At this stage to gain more experience with IT systems and tools	• High individual commitment of executives required • Emphasis on leadership and individual's experience • Knowledge sharing

4 Supply chain sustainability is the management of environmental, social and economic impacts, and the encouragement of good governance practices, throughout the life cycles of goods and services. The ongoing corporate social responsibility movement exerts pressure on firms to address ecological and social sustainability around the world (Förstl et al., 2010).

5 Due to consolidated demand of materials and services common to cluster residents, clusters attract suppliers that co-locate next to their largest demand centres (Sheffi, 2012).

6 Opture software is a software solution for corporate risk management.

7 Creditreform provides a network for credit reporting and debt collection services.

8 In inventory management, the consignment stock is managed as special stock in the company's inventory and is assigned to specific customers.

9 In the context of supply chain risk management, our definition of leadership involves establishing a clear vision, sharing that vision with others so that they will follow willingly, providing the information, knowledge and methods to realise that vision, and coordinating and balancing the conflicting interests of all members and stakeholders.

Table 4 Main Interview Findings in the Commercial Aerospace Industry

		Unit of Analysis		
		OEMs	First-Tier Suppliers	Second-Tier Suppliers
Dimensions	1) Source of Supply Chain Risk	• Market and liquidity risk, in particular related to foreign exchange rates and interest rates • Risk interrelations due to outsourcing and single sourcing	• B2B customer risk • Counterparty risk of the suppliers	• Demand and price risk • Operating risk regarding on-time delivery and quality • Risk interrelations such as customer satisfaction
	2) Risk Management Strategy: Proactive vs. Reactive	• Focus on proactive strategy and the sharing of risks & opportunities by using tools like incentive contracts and supplier collaboration • Reactive tools such as contingency planning and disaster management	• Emphasis on proactive, such as supplier collaboration through improved confidence and continuous coordination • Focus on the strategic level of cooperation and the long-term orientated relationship	• Both reactive and proactive strategies • Proactive tools such as product design and delivery management • Reactive tools such as resource utilisation and risk scenario analysis
	3) Risk Management Coverage and Depth along the Supply Chain	• Gaining experience on managing second- and third-tier suppliers • Building win-win relationship with suppliers • Lack of network visibility of second- and third-tier suppliers	• Mainly first-tier, selected second-tier if this is required by OEM • Sharing the result of risk evaluation with suppliers • Price risk transfer to suppliers	• Covering only first tier • Competitive relationship with suppliers • Very limited sharing of information regarding supply chain risks with suppliers
	4) Risk Management Process	• Early involvement of supplier • Early warning indication (quality, delivery, finance) • Sharing risks & revenues with suppliers • Supplier network management	• Supplier risk scorecard • Lack of sufficient re-evaluation of the residual risk	• Supplier segmentation • Regular performance review for key suppliers • Usage of supplier risk scorecard • Lack of sufficient re-evaluation of the residual risk
	5) Risk Management Systems and Tools	• Enterprise Risk Management (ERM)[10]	• ERM • Risk-monitoring Dashboard[11] • KPIs	• JDA Planning[12] • Internal database of best practice or lessons learnt
	6) Risk Management "Soft" Parameters: Resources, Culture, Leadership[9], Communication, etc.	• Based on high commitment of executives • Emphasis on leadership and individual's experience knowledge sharing	• Concept of risk ownership and role responsibility • Emphasis on effective communication with suppliers	• Constrained corporate resources • Lack of cross-functional and cross-division communication of risk • Risk culture building in process

10 Enterprise risk management (ERM) in business includes the methods and processes used by organisations to manage risks and seize opportunities related to the achievement of their objectives (Committee of Sponsoring Organizations of the Treadway Commission, 2004).

11 The risk-monitoring dashboard helps define and visualise the risk management decision-making process and provides data integration, risk reporting and progress monitoring.

12 JDA's software and services provide planning, optimisation and execution solutions for supply chain management.

3.2 Supply Chain Risk Profiles: What

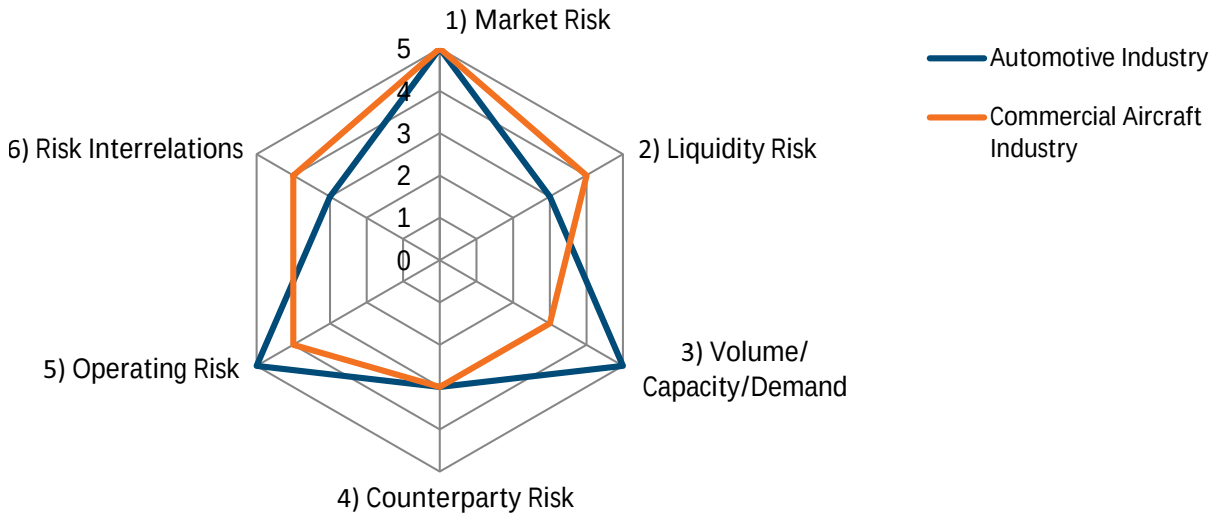
In section 1.3 (Definitions), we divided the supply chain risk into six types. Our interview findings showed that the top three risks that absorb the most corporate resources and demand the most managerial involvement in the automotive industry are market risk, operating risk, and volume/capacity/demand risk. By contrast, in the commercial aerospace industry, besides market risk and operating risk, liquidity risk and risk interrelations also provoke significant concerns from management.

To be more specific, market risk – the risk of losses in situations arising from movements in market prices – caused the most concern within our interviewee group from both industries. We also found that internal risks, especially business and operational risks, such as raw material supplier failure, product quality failure, finished product manufacturing failure, and the inability of counterparties to meet contractual obligations rank next in terms of causing concern to those interviewed from both industries. Market risk, operating risk and demand risk are the three most significant risk sources for companies from the automotive industry. In comparison, liquidity risk and risk interrelations seem to absorb more attention and engagement from their counterparts from the commercial aerospace industry.

The interviewees' perspectives of the emphasis placed in their organisations on different types of supply chain risk are shown in Figure 4. The 0 to 5 scale measures the extent of the interviewee's involvement in the corresponding risk category, in which 1 represents no involvement and 5 the highest degree of involvement.

In addition, we found that risk events with straightforward and tangible consequences seem to attract more attention from managers than those with severe, but hidden or non-quantifiable, impacts. We believe there are two major explanations here. Firstly, managers are likely to have experienced these risks several times in their careers and thus feel empowered to mitigate them. This is the "risk comfort zone," a set of frequently occurring, more preventable routine business risks. As a result of the frequent occurrence of such risks, organisations are equipped to analyse and mitigate them. Secondly, the performance appraisal system for the manager may also have a direct impact on the manager's risk priority setting. As one of the informants said, managers would hardly be given credit for managing risks that didn't happen or have invisible impacts. Managers are driven to fulfil their work missions by solving the most urgent and important supply chain risks, and thus there is less capacity or resource availability for investing in safeguarding against those hidden risks or risks with non-quantifiable impacts.

Fig. 4 Industry Comparison: Supply Chain Risk Profiles



3.3 Supply Chain Risk Sources/Drivers: Why

As stated in the previous section, market risks and internal risks, especially business and operational risks, are the most significant risk sources for both industries. In our interviews, we discovered that among a number of factors that contribute to an increase in the risk of a supply chain disruption, the most decisive source or driver is the global nature of today's supply chains. The evolving global nature of supply chains and business models, such as just-in-time, lean management, single-sourcing, outsourcing and offshoring, has led to changes in distributed areas of supply chain risks, which is the common feature being researched here.

In response to the trend of globalisation and global competition, our interviewed companies were found to have undertaken a variety of business practices to improve cost efficiency. Since the 1990s, focusing on the supply chain has brought about improvements in cost efficiency (Christopher and Lee, 2004). Leaping ahead, companies started to implement concepts streamlining supply chain processes (Childerhouse and Towill, 2003), such as just-in-time, just-in-sequence, virtual inventory and reducing the number of distribution facilities in order to create lean supply chains (Svensson, 2004; Thun et al., 2007). The lack of safety stock and reduced resilience in responding to sudden and unanticipated changes in demand become the first major drivers of supply chain risks faced by practitioners.

A second trend resulting from the globalisation of supply chains is outsourcing and offshoring. Outsourcing and offshoring increase the dependency of companies along the chain and the complexity of the whole supply chain network. Thus, it is hard for companies to gain a holistic and transparent picture of the entire supply chain network. The more complex a network is, the more interfaces there will be, and the greater the vulnerability (Peck, 2005). For instance, in 2013 major Japanese automotive OEMs recalled nearly four million vehicles worldwide due to a safety problem with airbags supplied by the Takata Corp. (Financial Times, 2013). According to our interview subjects from the automotive industry, similar car recalls are almost never caused by the manufacturer's own engineering lapses, but by a deviation in some material or process at a first-, second- or even end-tier supplier.

A third trend also stems from the globalisation of supply chains, which is characterised by longer shipping distances and the heightened complexity of trade. Companies have to account for factors such as currency shifts, political unrest, cultural differences, piracy and natural disasters. Due to the global nature of today's business, external events such as terrorist attacks, earthquakes and floods in one region can have ripple effects and thus jeopardise the whole supply chain. Such catastrophic events have reinforced the awareness of vulnerability along the entire supply chain for manufacturing firms (Knemeyer, 2009), downstream in dealing with customers and upstream in dealing with suppliers (Jüttner, 2005). As reported by our interviewees, external environmental risk together with the growing market uncertainty of demand and the shrinking of product life cycles, makes the job of matching supply with demand more complex than ever before. For instance, the 2010 volcanic eruptions in Iceland forced about twenty countries to close their airspace and the supply chains of our case study companies were unable to deliver parts to OEMs and end customers on time, which in turn caused certain negative impacts on the normal business operation and customer satisfaction.

3.4 Gap Analysis: How

As a result of insights gained from our interviews and the literature review, we identified four significant gaps between the practical realities of the business world and what is proclaimed as being the best practice in supply chain risk management in academic works. These gaps reflect four major supply chain risk management domains, namely, the coverage and depth of the supply tier management system; the process of supply chain risk management, especially concerning the residual risk; the approach of supply chain risk assessment using quantitative methods; and the balance between IT systems and "soft" corporate resources in supply chain risk management.

Our interviewees agreed that supplier management practices adopted by OEMs have an impact on first-tier suppliers'

1

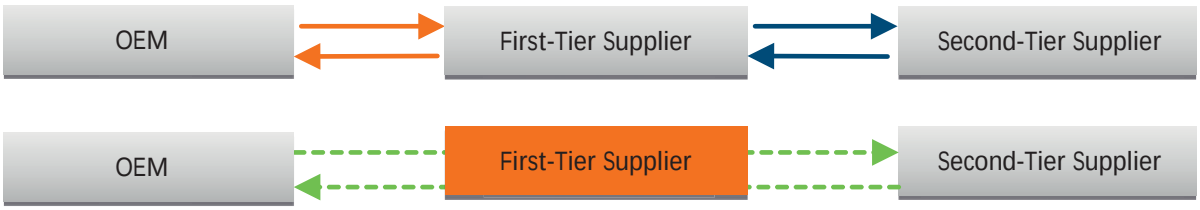
First-tier vs. Multi-tier Supply Chain Risk Management

Gap

Supplier risk management is often simplified as direct first-tier supplier risk management, which neglects the risk interaction and intersection with multi-tier suppliers. This is found to be more common in the automotive industry than in the commercial aerospace industry.

performance, which then, in turn, impact on the OEM's quality and delivery performance to the customer. Similarly, the way in which first-tier suppliers communicate and manage second-tier suppliers shapes the performance of second-tier suppliers and ultimately influences how first-tier suppliers perform. In practice, the implementation of single-tier and/or multi-tier supply chain risk communication falls into two categories. As Figure 5 shows, about fifty per cent of the OEMs communicate only with first-tier suppliers. The flow of information and communication is indicated by the red solid lines in the diagram. Although there is information and communication exchange between first-tier suppliers and second-tier suppliers, as indicated by the blue solid lines, there is the lack of a direct link between OEMs and second-tier suppliers in this regard. This practice is more prevalent for the automotive OEMs than for the commercial aerospace OEMs. Although automotive OEMs require their first-tier suppliers to regularly evaluate the second-tier ones as part of the performance evaluation of the first-tier suppliers, OEMs normally do not actively engage in further direct communication with their second-tier suppliers.

Fig. 5 Tier System of Supply Chain Risk Communication in Practice



Definition:

- Red/blue solid line:
  Arrow pointing to the risk management target
- Green dashed line:
  Arrow pointing to the final target of the risk management via the medium
- The block in orange:
  The medium for the risk management

The other half of the surveyed OEMs systematically monitors their second-tier suppliers via first-tier suppliers. Companies take a direct approach to second-tier supplier management and development by requiring suppliers to acquire goods and services from specific lower-tier suppliers and under specifically defined conditions. Companies sometimes also work directly with first-tier supplier alliance partners in solving second-tier suppliers' problems, designing supplier selection and certification programmes and implementing alliance development strategies. The information and communication flow between OEMs and second-tier suppliers runs via first-tier suppliers, as indicated by the green dashed lines.

Choi (2001) points out that even large organisations with sophisticated supply chain management practices do not have visibility over their own supply chain. As one of the company representatives explained in the interview, "It is not our job to monitor the risk of our second-tier suppliers, so we leave it to our first-tier suppliers to manage their lower-tier suppliers. And we are going to stick to this." In the end, the fundamental limiting factors for such practices are the significant amount of resources required and the executive commitment (Becks, 2010).

As pointed out by Frohlich and Westbrook (2001) in their study "Arcs of Integration: an International Study of Supply Chain Strategies," the arcs of supply chain risk management integration may extend to upstream and downstream supply chain partners. It is either considered as a narrow arc of integration with little integration of multi-tier suppliers, or a broad arc of integration with extensive integration of multi-tier suppliers along the whole chain. However, one decisive premise of the implementation of the integration is that companies have to integrate internally first before they can engage in aligned supply chain risk management tasks with their external partners, such as multi-tier suppliers and business customers. The "Arcs of Integration" concept is illustrated in Figure 6.

In our interviews we found out that OEMs in both automotive and commercial aerospace industries have a broad arc of integration. However, automotive OEMs have a stronger tendency to integrate and collaborate with only first-tier suppliers, whereas the commercial aircraft OEMs are more inclined to integrate directly and/or indirectly with both first-tier and second-tier suppliers.

Growing evidence indicates that the higher the level of integration and collaboration of multi-tier suppliers, the greater the potential benefits, both in terms of capturing the opportunities and mitigating the risks. There are three major benefits.

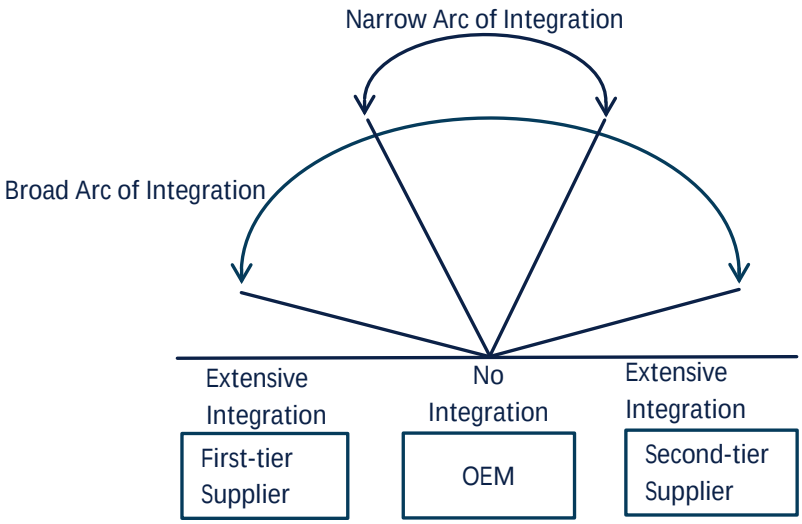
Firstly, broader integration and collaboration facilitate more seamless product launches. Close communication and coordination across multiple tiers of the supply base ensures that rapid production accelerates smoothly and cost effectively, especially in the product launch phase.

Secondly, direct multi-tier communication and information exchange helps to avoid or minimise the problems of asymmetric information and thus increases the velocity of information flow so that the quality of information used in the planning and operation processes will improve, and the brand owners can receive delivery commitments on an ongoing basis. This effectively reduces the risk of shortages, improves forecast consensus and reduces lead times, ultimately generating higher levels of service.

Thirdly, the overall performance of the supply base can be improved. In order to measure the performance of strategic suppliers, OEMs need to be connected to them, regardless of the tier. By tapping into supply and demand events, they can measure ongoing performance metrics, plus key metrics such as effectiveness in delivering against demand and flexibility in responding to changes.

Lastly, multi-tier visibility creates a resilient and agile supply chain. With visibility into operational disruptions across the extended value chain, companies are able to see—and respond to—sources of supply chain risk before operations and supply chain performance are impacted (Becks, 2010).

Fig. 6 Arc of Supply Chain Risk Management Integration



2

Traditional vs. Dynamic Process of Supply Chain Risk Management

Gap

Re-evaluation of the residual risk is not fully integrated in the supply chain risk management process in either of the studied industries.

According to ISO 27001, the residual risk is the remaining risk once the initial risk is mitigated. In our interviews, we found that in both industries studied, the four traditional steps ascribed to managing supply chain risks include: risk identification; risk assessment; development of risk mitigation strategies and tools; and execution of risk management capabilities. Most of our interviewed organisations do not integrate the re-evaluation of the residual risk into the dynamic risk management process, although it is considered by most interviewees as a proactive and recurrent assessment step. We did not find a clear co-relationship between this phenomenon and the sector in question.

The residual risk is revealed during the risk management process. After the identification and assessment of the risks, companies need to develop strategies for mitigating them. Once companies execute the risk management capabilities, it is not always possible or realistic to completely eliminate all the risks. Therefore, some residual risks remain at a certain level.

In our research we have seen that the automotive industry has implemented routine strategies for monitoring the development of their residual risks. This practice is more prevalent with OEMs compared to first- and second-tier suppliers. Smaller suppliers in particular do not show such recurring practices. In the commercial aerospace industry the situation is similar. However, the presence of residual risk, especially that associated with technical failure, is very closely monitored and is frequently reassessed. However, commercial risks are not managed according to this process.

The key consideration is that the risk mitigating effort actually reduces the corporate impact and does not just move the risk to another similarly high level quadrant. Thus, once the mitigation step has been identified and executed, the risk

should be reassessed, taking into account its effect and frequency. Its impact should then be recalculated to see whether the mitigation and execution effort has really made an acceptable difference. The mitigation efforts are often resource-intensive and a major outlay for little or no residual risk should be challenged.

Basically, there are three options once the residual risks have been identified. First, if the risk is below an acceptable level, then the company need do nothing – managers need to formally accept them. However, if the risks are above an acceptable level, then the company needs to find new (and better) ways to mitigate them – this also means that reassessment of the residual risks is essential. Finally, if the risks are above the acceptable level, and if the cost of decreasing them would be higher than the impact itself, then the recommendation to managers would be that these risks should be accepted even if they are high. A systematic approach such as this ensures that managers are involved in the most important decision-making and that nothing is overlooked. After all, the management board is not only responsible for the bottom line of the company, but also for its viability (Kosutic, 2012).

3

Qualitative vs. Quantitative Risk Evaluation

Gap

Many companies from both industries rely on a qualitative view of evaluating risks without real quantification.

As Taylor has already stated in 1999, "there is no doubt of the importance of quantitative models and computer based tools in decision making in today's business environment". As his work further states, this holds especially true for today's increasingly complex and global supply chains. According to Alvarenga (2012), anyone who claims to be managing supply chain risk without understanding subjects like real options, hedging, value at risk models, financial simulation, and so on, is more like a security guard than a real risk manager.

However, a common observation from our interviews was that managers are rarely trained in or practice quantitative concepts and methodologies for the evaluation and aggregation of risks across the supply chain. Thus, in these cases, decision-making can only be based on a qualitative view of supply chain risks. To underpin the significance of this issue, we wish to propose three major benefits that will assist companies in using quantitative methods in supply chain risk management.

Firstly, quantitative analysis can enhance the transparency of management decisions and provide accountability and objectivity to the policies of those in charge of supply chain risk management.

Secondly, the implementation of quantitative tools allows for quantitative analysis and comparisons. These comparisons can, for example, consist of different locations and their risk exposure, different business segments in the company, as a benchmark between business segments of different companies or comparing different technologies, methods or techniques to be implemented. As an example, quantitative methods can be used to measure the impact of risk mitigation actions such as hedging price risks or diversification of the supplier structure. On that basis, the efficiency of alternative risk mitigation actions can be compared both from ex-ante and ex-post perspectives.

Thirdly, thanks to rapid advancements in computer science and technology, the use of quantitative tools has becomes easier. Data processing, combining, complex modelling and calculations can be performed within seconds and even less proficient users can perform sophisticated analyses using current software programs and tools. It is much more difficult to provide an automated solution for processing qualitative data for supporting risk management decisions.

4

IT System and Tools vs. "Soft" Corporate Resources in Supply Chain Risk Management

Gap

Many companies from both of the industries studied rely largely on IT systems and tools and consider them as the enablers of supply chain risk management as opposed to softer factors.

Among our interviewees, there was a high level of awareness of supply chain planning tools and techniques. Over the last eighteen months, about two-thirds of our sample companies had either upgraded existing, or installed new, technology to improve their risk management systems.

However, the success of a risk management system depends on many other factors, such as the integration and compatibility between system and business processes, the strategy for using the technology, and the role of leaders.

In addition, the risk management system depends on the context in which it is being applied and important dimensions include trust between partners, information sharing, personal exchanges, and interactions, rather than the sophistication of the approach (Ritchie and Brindley, 2007).

Of all the aspects which influence the success of supply chain risk management, a particularly valuable one is effective leadership. The difference between supply chain management systems and tools and a great leader is that systems and tools exist to facilitate activities and provide a framework for people to follow when disruption occurs, whereas a great leader is often necessary to ensure that these systems are working properly and can deliver alternatives when the system fails (Choi, 2011).

However, different risks require different approaches. To be more specific, risk management systems and tools are most effective when disruption is not severe, has occurred before and can be tackled with plenty of resources, such as a quick and accurate information flow. In comparison, if the risk is severe and unfamiliar, personal guidance and direction will be more necessary. This is where an effective leader is required. Such an individual is more efficient at leveraging limited resources, and is more suited to addressing disruption where communication between organisations is poor. In other words, systems cannot predict every risk, and flexibility offered by human intervention is more capable of making on-the-spot decisions (derived from the research project at the Arizona State University, 2011).

4 Recommendations for Practical Implementations

The strategies and approaches adopted by companies to manage multi-tier supply chain risks vary. There are various factors which contribute to these differences. For instance, the ability of an OEM to be alerted to and to report force majeure risk of a sub-supplier can differ from social risk. And an OEM's cognitive perspective of risk may be more similar to that of its sub-supplier in the same region than to that in a different continent. Other factors, such as executive commitment, corporate risk culture and the knowledge sharing system, may also have an impact on risk management strategies and tactics for sub-tier suppliers.

Despite the complexity of multi-tier supply chain risk management, there is a growing number of successful examples that demonstrate its feasibility in practice. Current technologies such as radio-frequency identification, enterprise resource planning and general packet radio service are becoming important tools for supply chain network management (Tang, 2006b; Vanany et al., 2009), and future technologies are expected to make a big impact on the visibility and traceability of supply chain networks (Ghadge et al., 2012).

In this part, we recommend several concepts for resolving the four gaps observed in practice, namely, 1) the gap between first- and multi-tier supplier risk management, 2) the gap between traditional and dynamic risk management process regarding the treatment of residual risk, 3) the gap between qualitative and quantitative supply chain risk management methods and 4) the gap between IT software and tools and "soft" corporate resources of supply chain risk management.

Our first recommendation is the Three-Circle (3C) Model, which helps to resolve the first gap. By using the 3C Model, managers can better identify risks associated with a company's multi-tier supply chain partner. This model can be applied in both industries, but it is more applicable for the automotive industry, as we have found that in the automotive industry there is a stronger tendency for supply chain risk management to be targeted only at the first-tier supplier. Based on the input data generated from the 3C Model, a Risk Portrait of the Multi-Tier Supply Chain Partner Model can be built. This Risk Portrait increases risk visibility and comparability for the selected multi-tier supply chain partner.

The second recommendation is the Multi-Tier Supply Chain Risk Management Circle Model, which treats the risk management process as a dynamic system and its target is to solve the residual risk. It provides managerial guidance on which residual risks should be re-evaluated after mitigation strategies have been conducted and how this can be achieved. This could be applied to both of the industries studied.

Our third recommendation is the implementation of quantitative tools for supply chain risk management. The quantitative approach for assessing multi-tier supply chain risks involves five basic steps, namely, prioritisation of supply chain risks by using tools such as Risk Mapping; quantification of the risk impact; modelling joint risk factor dynamics; calculating risk probability distribution; and aggregating supply chain risks.

Finally, we advocate a balanced supply chain risk management mechanism which emphasises the importance of both IT systems and "soft" corporate resources such as leadership and intra-organisational risk communication.

4.1 Risk Identification and Assessment: The Three-Circle Model

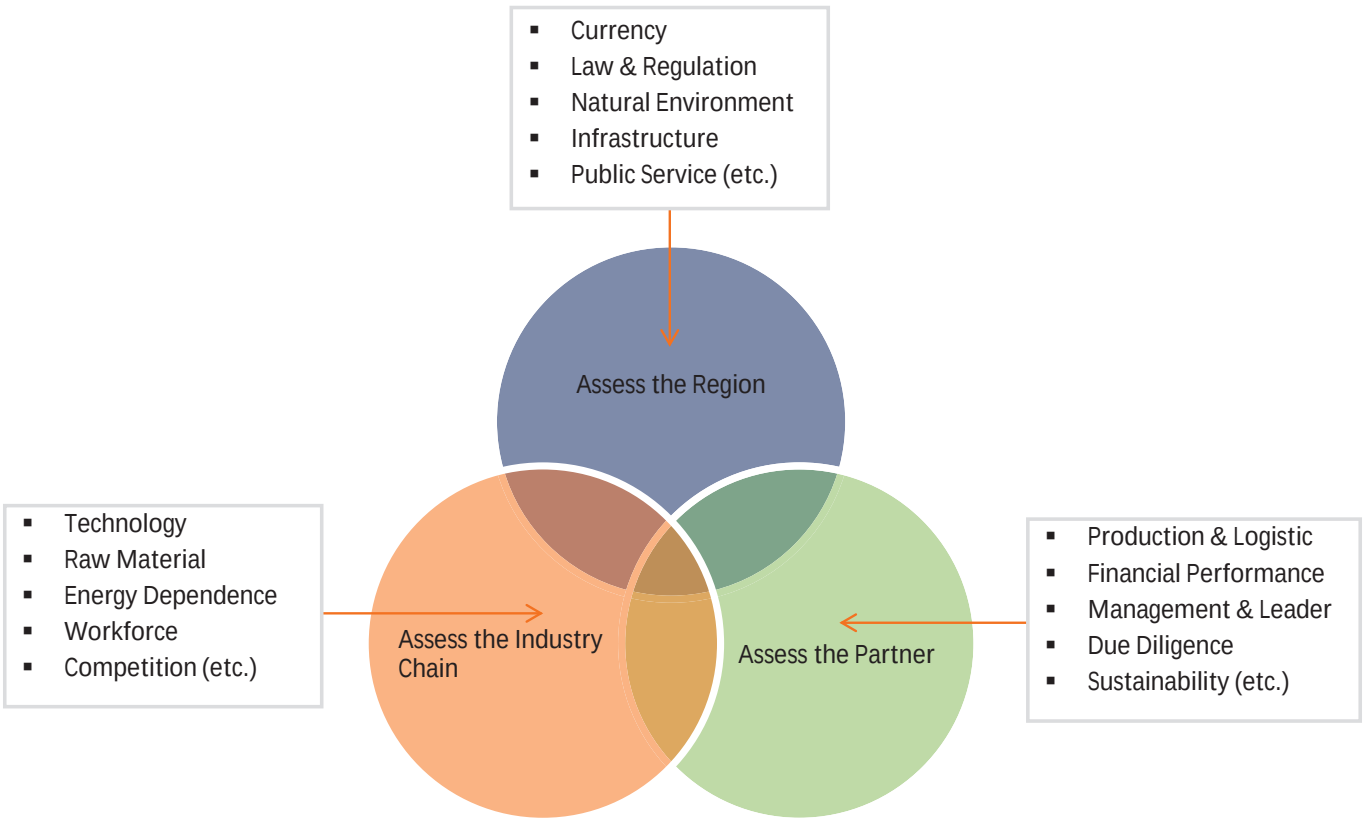
Our first recommendation focuses on solving Gap 1 (Section 3.4). This can be applied to both industries, but it is more applicable to the automotive industry as we found in our interviews that its supply chain risk management tends to target only the first-tier supplier whereas this is not such a common approach in the commercial aerospace industry.

The risk identification and assessment stages are particularly critical to successful risk management as they detect organisational exposure to uncertainty (Neiger et al., 2008). Without a comprehensive knowledge of existing and potential disruption, appropriate actions for avoiding supply chain vulnerability will lose its evidential base. There are various approaches or models for tackling supply chain risks. Based on prior research and practical approaches, we recommend that companies adopt the 3C Model for supply chain risk identification for multi-tier supplier management, as illustrated in Figure 7. The 3C Model identifies and analyses risks from three angles, namely, location, industry and the supply chain partner. It also has unique practical implications. Managers can use it to develop company-specific risk management programmes and to create strategies and management responses that can influence and enhance their relationships with multi-tier suppliers. The model is easy to implement and facilitates proactive supplier risk management.

In practice, the items for examination should best reflect the purpose of multi-tier supply chain risk management. The time gap between two updates can be large. As other parameters such as financial performance and logistics can be more prone to fluctuations, they will need updating more frequently.

Compared to the other risk models of supplier risk assessment, the 3C Model has three unique advantages. Firstly, it provides an operational and holistically balanced approach to tackling risk types, drivers and their correlations in the context of multi-tier supplier management. Vast amounts of data and lots of other corporate resources are needed to generate the risk map of multi-tier supplier demands. For automotive OEMs, the base of the pyramid tier-system consists of tier four suppliers who form and perhaps own much of the intellectual capital that is required to produce excellent components. Many of those lower-tier suppliers own patents, have customised machinery and are family owned. Working with these lower-tier suppliers is the key to making the necessary changes in a timely and efficient manner. However, the current frameworks of supplier risk assessment do not fully integrate the lower-tier suppliers in a systematic way that takes into account both the regional and industry chain-related context.

Fig. 7 Three-Circle Model: Mapping the Risk of Your Multi-Tier Supply Chain Partner



Secondly, the three-dimensional view allows a more nuanced assessment of the major risk categories for each supplier and sub-supplier relationship. Although the 3C Model is organised into overlapping segments, it can be operationalised based on a recurring and responsive process, which compensates for shortcomings in the identification process, such as the overlapping or bypassing of elements.

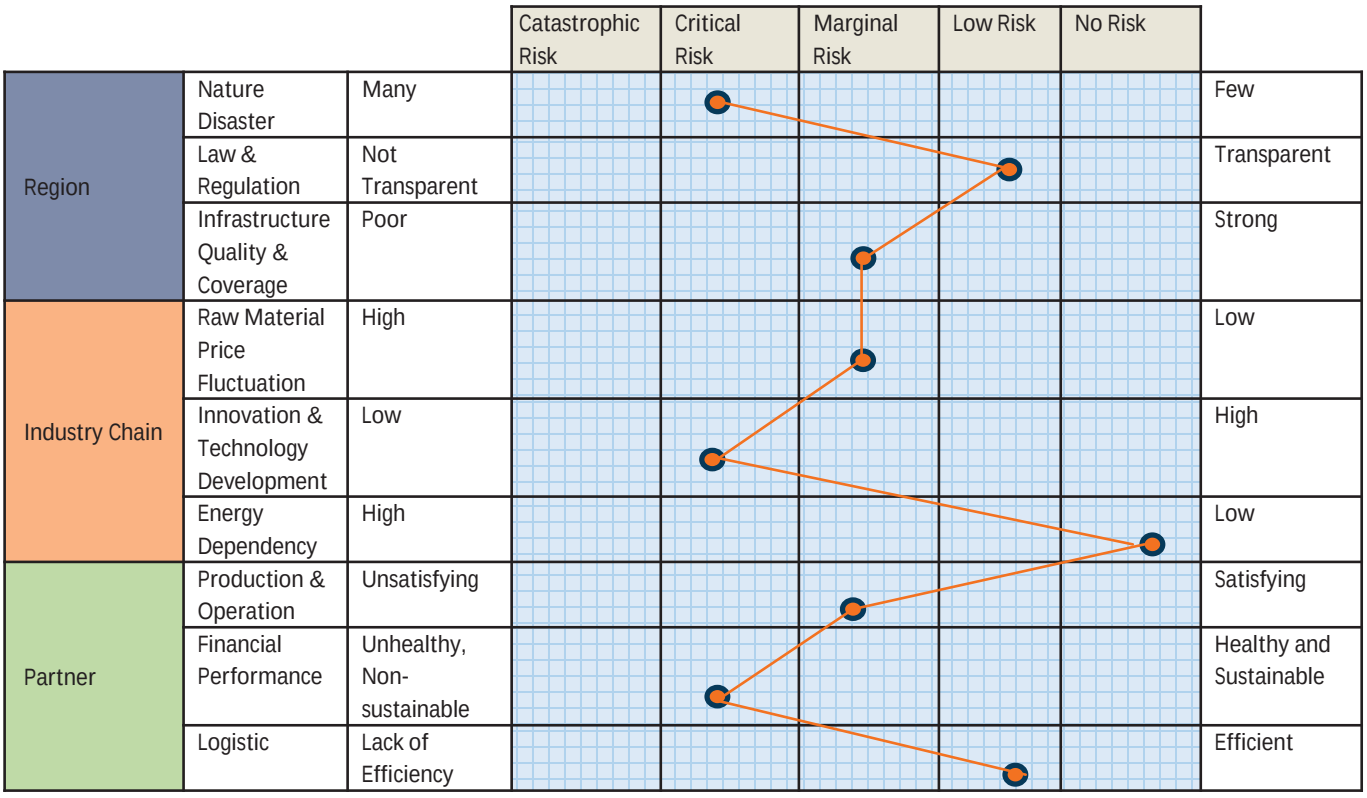
Lastly, the 3C Model also pays additional attention to the assessment of due diligence. According to our interviews, less than fifty per cent of the interviewed companies have due diligence in place to alert them to supply chain risk. The supplier risk model is often built upon modelling historical financial performance and trends as an indicator of future supplier financial performance. However, supply chain operations change more quickly than financial projections. Especially in emerging countries, financial and accounting practices and standards vary, which makes a standardised, formulaic risk-modelling approach based purely on financial calculations less reliable.

The appropriate nature and extent of due diligence will depend on individual circumstances and be affected by factors such as the size of the organisation, the location of its activities, the situation in a particular country and the sector and nature of the products or services involved. These factors can be reflected by two dimensions of the 3C Model, namely, Region and Industry Chain. These challenges can be met in a variety of ways, including but not limited to (OECD, 2013):

- Industry-wide cooperation in building capacity to conduct due diligence.
- Cost-sharing within the industry for specific due diligence tasks.
- Participation in initiatives on responsible supply chain management.
- Coordination between industry members who share suppliers.
- Cooperation between upstream and downstream companies.
- Building partnerships with international and civil society organisations.

After the completion of risk identification and risk assessment, we recommend that managers delineate the risk profile

Fig. 8 Risk Portrait of Your Multi-Tier Supply Chain Partner (Example)



Definition:

- Catastrophic: catastrophic impact.
  The risk brings about discontinued business.
- Critical Risk: serious impact.
  The risk causes long-term difficulties.
- Marginal Risk: medium impact.
  The risk causes short-term difficulties.
- Low Risk: minor impact.
  The risk will lead to single small losses.
- No Risk: no impact.
  It means the risk is insignificant for the company.

of the supply chain partner in a visual way, as shown in Figure 8 – Risk Portrait of Your Multi-Tier Supply Chain Partner.

The Risk Portrait serves as a decision-making support tool that enables companies to more easily identify bottlenecks and critical nodes within the risks for multiple suppliers. To illustrate this, take one automotive OEM as an example. Suppose this OEM has only two second-tier suppliers which produce a critical component. The Risk Portraits show that the highest risk with the potential catastrophic impact faced by both of them is law and regulation. Once this critical information is acquired by the OEM, the OEM can decide to utilise its capabilities and resources to develop either proactive or reactive strategies to avoid or minimise the negative impact caused by risks of the second-tier suppliers. In this example, we only take two suppliers as an example. However, if the number of suppliers is scaled up to a hundred or a thousand, it will become difficult for the OEM to compare the differences and similarities of the risk portraits manually. Thus, the next step in developing the conceptual Risk Portrait Model is to add software programs so that managers will only need to assign a value to the risk and the risk portrait can be automatically generated and multiple risk portraits can be easily compared.The parameters listed in Figure 8 are for demonstration purposes. The choice of parameters below each category may differ from company to company. The result of the Risk Portrait needs to be updated regularly in order to draw comparisons between the historical and the current evaluations of a specific supply chain partner or between two or more partners. Moreover, this specific assessment allows the derivation of more nuanced and specific countermeasures for tackling risks compared to simply multiplying probability by business impact to derive a standard risk indicator.

4.2 Risk Management Process: Multi-Tier Supply Chain Risk Management Circle

Our second recommendation focuses on solving Gap 2 (Section 3.4). The model recommended here concentrates on integrating the re-evaluation of the residual risk in the supply chain risk management. This model can be applied in both of the industries studied.

Based on the existing scientific framework in Supply Risk Management Processes developed by Förstl et al. (2011), we have developed a five-stage framework for multi-tier supplier risk management, incorporating risk identification, risk assessment, risk mitigation strategy development, risk management execution and residual risk re-evaluation. It builds on Ritchie and Bridley's conceptual approach and the approach of the Association of Insurance and Risk Managers (AIRMIC).

We argue that the supply chain risk should be managed as a dynamic process. A dynamic process requires that risk management objectives, strategies, tactics and priorities fit into the dynamic external and internal business environments. It provides three suggestions for practice.

To implement this model, companies in both industries researched here, especially those with multiple product lines, divisions or brands, need to firstly define their supply chain risk management so that they are distinct from a one-for-all risk management strategy and implementation plan. To a large extent, the majority of the companies in our case study belong to this category, as they have multiple product lines and an internal customer base.

Secondly, to successfully implement the tool, managers should be aware that the objective of supply chain management may evolve with time. Due to organisational and environmental changes, companies, even with rather simple product lines, will be exposed to different supply chain risks at different times. Thus, supply chain risk management should be regarded as an organic process. For the majority of our interviewed companies, cross-border geographic expansion and executive restructuring has taken place in the last five years. For instance, as one of the world's leading suppliers of high-precision metal components for the automotive industry, one company interviewed opened its wholly-owned subsidiary in Suzhou, near Shanghai, in 2009. As a result, the company has had

Fig. 9 Multi-Tier Supply Chain Risk Management Circle

the opportunity to supply numerous European customers at one of its major foreign sites and also has access to new customers in Asia. Therefore, it is vitally important to update supply chain risk management strategy and practice in order to reflect the dynamic internal and external operating environment. Thirdly, risk management procedure should be a closed-loop circle, as shown in Figure 9. In this dynamic process, supply chain risk management starts at risk identification but does not end with the execution of risk management strategies and tactics. In our model, we advocate risk management execution being the starting point of the next round of risk re-evaluation. Based on the new updated result generated by risk re-evaluation, risk mitigation strategies and tools should be renewed accordingly.

4.3 Risk Measurement and Aggregation based on Quantitative Approaches

Our third recommendation advocates the use of quantitative approaches for the measurement and aggregation of supply chain risks. The emerging importance of the quantitative perspective is explained in Gap 3 (Section 3.4).

Risk Mapping – Pitfalls and Avoidance Strategies

The application of quantitative approaches as part of day-to-day risk management usually requires significant effort. It is therefore reasonable to prioritise supply chain risks according to their importance for the specific business and to consider the application of quantitative measurement only for those risks that receive top priority. In order to achieve this systematically, a Risk Map or Risk Portrait can be established (Section 4.1) which reveals high-priority risks. Those risks are then represented by so-called risk factors which can be directly observed as quantities (e.g. fluctuation of the EUR: USD exchange rate; change in the turnover volume of a certain product or the rise and fall of client defaults over a certain period of time).

Although intuitive, the practical application of risk mapping for supply chain risks should include safeguards. The pitfalls and avoidance strategies of risks are outlined in Table 5.

Quantitative Impact Assessment

As a result of the risk mapping procedure, standardised movements of risk factors representing highly prioritised risks can be assigned with their related (qualitative) impacts, as summarised in Table 5. As the first step towards quantitative risk measurement, the above-mentioned impacts have to be quantified, or they need to be given a 'price tag'. For this purpose, the various contributions of losses associated with a certain risk factor movement (e.g. a supplier default or a shift in a particular market price) are determined taking into account all relevant parts of the supply chain. Some examples are illustrated in Figure 10. As a quantitative reference for "loss", for instance, the future deviation of Earnings before Interest and Tax (EBIT) or the cash flow from a pre-determined target figure can be used. The deviation will then refer to a certain period of time in the future, for example, a fiscal year.For each loss contribution, a typical loss amount should be determined independently by at least two different experts. Where expert assessments vary significantly, expert interviews can be repeated if necessary.

Since the assessment of an impact remains inherently subjective in spite of the involvement of independent experts,

Table 5 Common Pitfalls of Risk Mapping and Proven Strategies to Mitigate and/or Avoid Them

Risk Mapping – Pitfalls and Avoidance Strategies	
"Unknown unknowns": failure to identify essential risks	• Systematically analyse risks based on standardised risk categories for the business following a strict top-down approach (e.g. counterparty risks client/supplier defaults) • Consider risks induced from a multi-tier supplier perspective, i.e. at least up to the second-tier supplier • Collect information on risks from experts for each part of the supply chain (e.g. procurement, production, sales) based on a standard questionnaire • Collect information from historical loss events for own business and for third parties exposed to comparable risks • Permanently examine whether the risks which have led to historical loss events are properly represented in the risk map
"Known unknowns": misjudgement of the impact or probability of risks identified	• Represent the risks identified in terms of a minimum set of main risk factors without pronounced correlations in order to limit the complexity of the analysis and to avoid implicit risk concentrations (e.g. two market prices with highly correlated movements should be represented by a single risk factor) • Strictly separate the analysis of impact and probability • Assess (qualitative) impacts through standardised scenarios for the movement of all risk factors within a risk certain category (e.g. +/- 10 per cent shift in a certain market price or currency exchange rate) • Evaluate the (qualitative) probability of risk factor movements according to the standardised scenarios (e.g. low/medium/high) within a certain period of time

it is important to verify the consistency of those assessments with historical loss events ("back-testing"). For simplicity, we assume a linear dependence between risk factor movements and the associated impact. This means that if an adverse market price movement doubles, so too does the associated loss. Or if two clients default, the loss will be approximately twice as high as in the case of a single client default.

Modelling Joint Risk Factor Dynamics

As the final ingredient in the quantitative risk measurement, we have to find a model for probabilities (or more generally, probability distributions) of possible future risk factor movements. On that basis and taking into account the results of the previous section, the probability distribution for possible future loss events can be derived.

For example, the probability of a supplier default within one year might be estimated as x per cent. The probability of default can be determined using statistical methods based on key information from the supplier, such as financial data (i.e. balance sheet figures), behavioural track records (delivery reliability, etc.) and information regarding its dependence on its own suppliers (e.g. second-tier suppliers).

A common approach for estimating the probability of default is to use Artificial Neural Networks (ANNs), which are information processing systems inspired by the behaviour and architecture of biological nervous systems such as a human or animal brain. ANNs consist of a number of strongly interconnected non-linear processing units – neurons – which act as mathematical operators performing specific operations. In essence, the ANN can "learn" to predict supplier default rates from key information.

Assuming that supplier defaults are statistically independent, the probability of more than one default, i.e. a specific number of defaults, is described by binomial distribution (Deutsch, 2009). Given the typical loss amount associated with one supplier default, the probabilities of possible total losses resulting from several supplier defaults can be derived. Let us take another example. The future movements of market prices are often described by lognormal distributions (Deutsch, 2009). The parameters of those distributions, i.e. price volatilities, are usually derived from historical price movements. In turn, the associated loss distribution can be derived from the distribution of market price movements and the loss amount for the firm associated with a given price movement. The degree of dependence between future risk factor movements (e.g. market price fluctuations for two different commodities) is usually described by their correlation. If correlations between risk factor movements can be estimated, the joint probability distribution can be specified. For instance, the distribution for two different commodities defines the probability of any given simultaneous price movements for those commodities.

Fig. 10 Components of the Typical Economic Loss Related to a Supplier Default

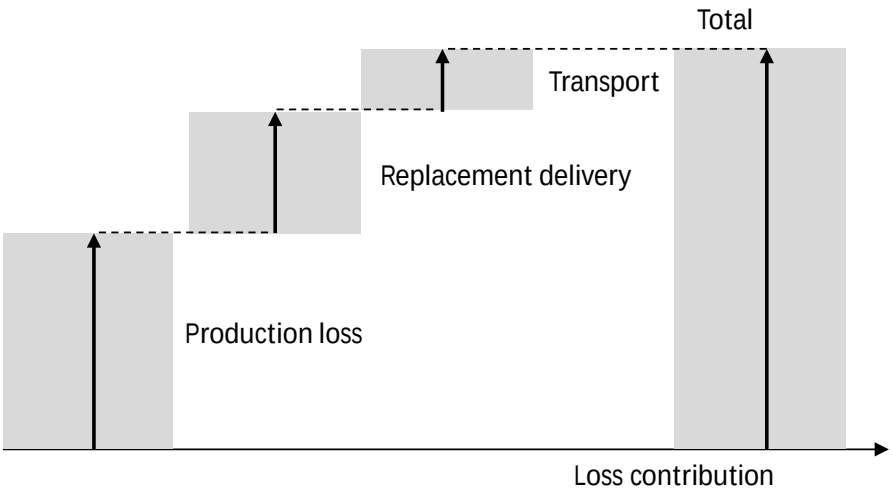
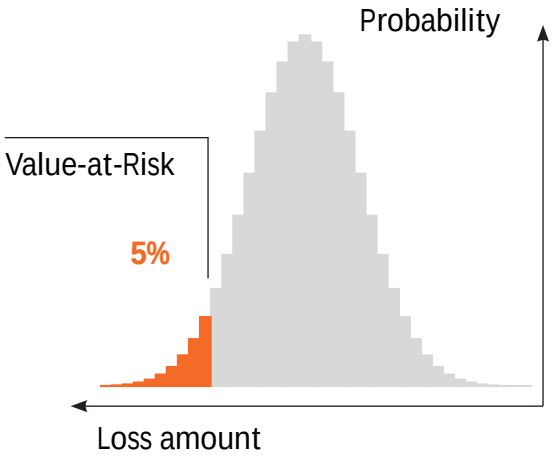


Fig. 11 Loss Distribution and Value-at-Risk for a Single Risk Factor



Quantitative Risk Measurement

Using the ingredients described in the previous section, we can derive the probability distribution of losses caused by future movements of a single risk factor over a certain period of time, as demonstrated in Figure 11.

The risk involved in distribution can be described by a single risk measure. A common choice is Value-at-Risk (Deutsch, 2009) which denotes, with a certain confidence, the loss level which will not be exceeded (e.g. ninety-five per cent) within a certain period of time. In other words, the actual loss will exceed the Value-at-Risk with a probability of five per cent,

i.e. in one out of twenty observations.

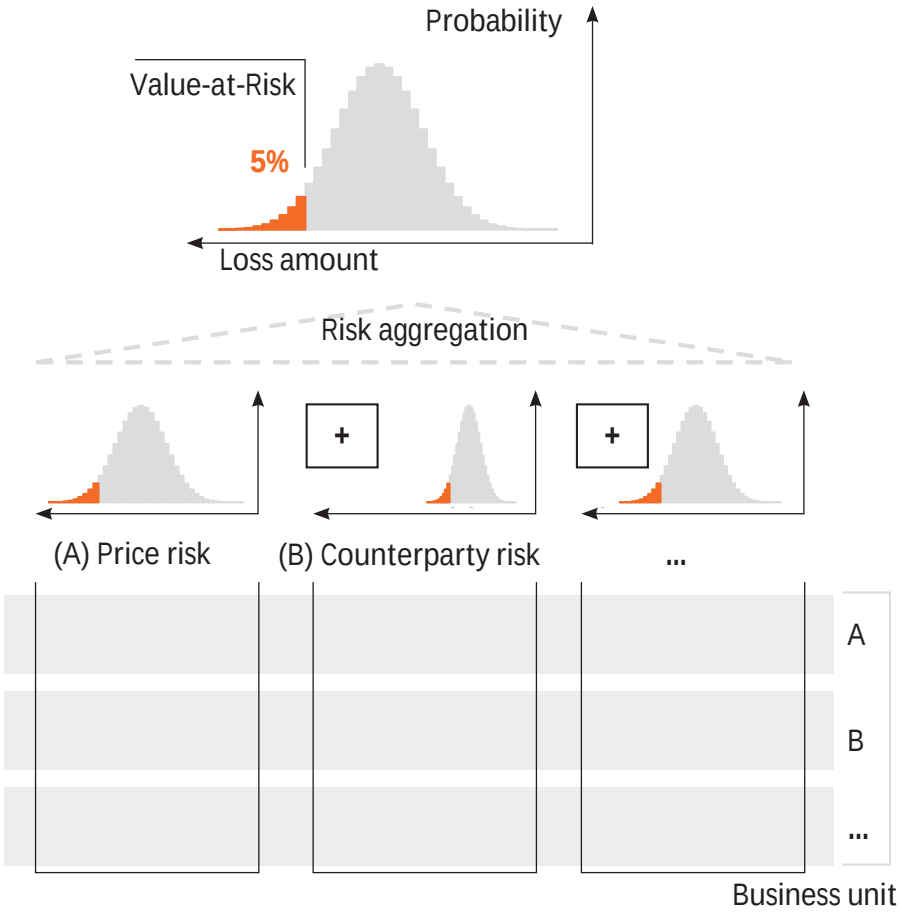
Value-at-Risk can be estimated analytically using parametric probability distributions. If there is no explicit analytical representation, then Monte Carlo techniques can be used, for instance, to simulate possible outcomes for future loss based on random numbers (Finke et al., 2010). For example, the Value-at-Risk for ninety-five per cent confidence can be estimated as the fifth percentile of the simulated outcomes for the future loss.

Aggregation of Supply Chain Risks

Aggregated loss distributions for multiple risk factors can be derived from the related distributions for single risk factors together with the correlations of these factors. Due to the complex structure of multi-factor distributions, it is uncommon to model those distributions directly based on parametric functions. Instead, aggregated risk measures such as Value-at-Risk are derived using Monte Carlo simulation techniques.

The aggregation of risks can be executed along different dimensions, in particular through type of risk (e.g. market price risk, counterparty risk, etc.) or by business unit, as illustrated in Figure 12. Thus, it is possible to analyse and track down contributions to supply chain risk from all areas. The knowledge gained in this process can then be used as a key ingredient for strategic decision making – from the choice of efficient risk mitigation techniques such as hedging to business and investment planning.

Fig. 12 Aggregation of Supply Chain Risks



4.4 Risk Mitigation and Execution: IT, Leadership and Communication

Our last recommendation focuses on solving Gap 4 (Section 3.4). Our findings show that many companies rely too heavily on IT systems and tools and consider them as the real enablers of supply chain risk management. This is a common phenomenon observed in both industries studied. Thus we recommend that both industries should find a balance between IT systems, the role of leaders and communication in managing supply chain risks.

IT systems and tools are not the master key for solving every supply chain-related risk. Too much dependency on such systems is risky in itself because it undervalues the role of leadership in situations where the system fails. As explained by Professor Lee, Director of the Stanford University "Global Supply Chain Management Forum," leadership in supply chains focuses on the innovative ways in which organisations can leverage the supply chain to create and capture the most value. This is in line with our definition of leadership in the context of supply chain risk management, which involves establishing a clear vision, sharing that vision with others so that they will follow willingly, providing information, knowledge and methods to realise that vision, and coordinating and balancing the conflicting interests of all members and stakeholders.

Boeing, for example, is relying on its first-tier global strategic partners to develop and build entire sections of the Dreamliner that are based on unproven technology (The New York Times, 2013). Any break in the supply chain can cause significant delays to the overall production process. In early September 2007, Boeing announced a delay in the planned first flight of the Dreamliner citing ongoing challenges including parts shortages and remaining software and systems integration activities. Even using Exostar, a web-

based planning system, to coordinate the supplier development activities, coordination is only possible when accurate and timely information is provided by different suppliers. For example, one of the first-tier suppliers, Vought, hired Advanced Integration Technology (AIT) as a first-tier supplier to serve as a system integrator without informing Boeing. AIT is supposed to coordinate with other second-tier and third-tier suppliers for Vought. Additionally, due to cultural differences, some second-tier or third-tier suppliers did not routinely enter accurate and timely information into the Exostar system. As a result, various first-tier suppliers and Boeing were unaware of the delay problems in good time, which made it difficult for Boeing to respond to these problems quickly (Tang, et al., 2009).

To be more specific, it is necessary to first understand the multi-dimensional aspects of a risk. These aspects can characterised through 1) severity – for example, meaning the extent to which the disruption causes the production line to stop; 2) unfamiliarity – how often the disruption has occurred previously; 3) resource limitations – whether the business division or the company has the financial means, managerial skills and information-sharing ability to respond effectively; 4) complexity – whether the disruption has an impact on single or multiple supply chains; 5) inter-organisational relationship context – how collaborative and amicable the relationships between the parties involved in the disruption are (Carey, 2011).

In the risk identification phase, especially when the risk is related to supply chain integrity, compliance, and quality control, or when the relationship with a remote partner is subject to differences in business and cultural contexts, it is not always the system but the employee at the front line interacting with the supply chain partner who could be the first to notice an unusual signal. In the risk handling process, especially when the risk is severe, unfamiliar and tough to forecast and monitor, it is more appropriate for this to be handled by people rather than by a system (Carey, 2011).

Through our interviews, the common challenge faced by most of the interviewed organisations is that supply chain risk management needs to be part of a job responsibility across different functions with all functions involved collaborating and communicating effectively. However, in practice, supply chain risk communication within an organisation is often fragmented and only occurs within one or very limited business units. As one of our interviewees from the automotive industry said, “The intro-organisational communication of supply chain related risk poses a big challenge in our corporation. Poor communication – particularly between business and technical experts – is a constant problem. Corporations are organised in hierarchies, in line roles; doing projects is different. Projects go across silos.”

Although the term integrated communication has widely been used to describe campaigns that combine advertising, marketing and public relations, we define integrated communications in the context of supply chain risk management more broadly as the application of analysis, communication and evaluation techniques to create and manage integrated, multi-faceted interventions combining information, instruction, collaboration, business process design, feedback and incentive systems to improve human performance in the supply chain management in order to achieve organisations’ desired missions and visions (Adopted from Gayeski and Woodward, 1996).

An integrated communication system is a system which breaks down the communication barriers between divisions and functionalities. Kiser and Cantrell (2006) stated that communication in effective supply chain management cannot be overemphasised. Nevertheless, “most literature revolves around inter-organizational risk sharing, but little is said about intra-organizational actions toward reducing risk” (Deleris, 2004).

The survey conducted by Massachusetts Institute of Technology (MIT) in 2010 which received 1,461 responses from over seventy countries provides more evidence in favour of the importance of effective communication. Its results showed that, globally, people do not share the same attitudes and priorities about supply chain risks and risk management practices. Due to these differences, it is not always an easy task to persuade all stakeholders to understand the risk itself and to make them recognise their role in the risk governance process and that, through being deliberately reciprocal, gives them an opportunity to express their opinion on it. Once the risk management decision has been taken by the managerial board, communication should explain the rationale for the decision and allow employees to make informed choices about the risk and its management, including their own responsibilities. Effective communication is the key to avoiding asymmetric information exchange and creating trust in risk management.

In order to ensure the effectiveness of the framework, it is necessary to integrate it into the company’s daily routines, proactively and continuously. In addition, the risk management approach and its results need to be communicated efficiently and promptly to assure risk awareness and readiness among all employees.

Identification of a risk may appear to be a routine task that is signalled by the system. However, many crises are much less obvious, such as a supply chain partner’s financial distress. Therefore, the responsibility is to identify and detect a potential risk before the actual disruption occurs. To make this happen, communication barriers between functional divisions and different geographical areas within the supply chain should be broken down. In other words, the overall transparency of supply chain risk communication takes precedence over local transparency. The whole is greater than the sum of the parts.

5 Conclusion

In this empirical research, we have studied supply chain risk management in both automotive and commercial aerospace industries. Our interview findings include firstly, that at present, industrial environment supplier risk management is often simplified as first-tier supplier risk management; secondly, re-evaluation of the residual risk is not commonly practiced in the supply chain risk management process; thirdly, quantitative supply chain risk management approaches are not widely applied in practice. Next, companies tend to be heavily reliant on IT systems for managing supply chain risks instead of achieving a sustainable balance between IT systems and "soft" resources such as effective leadership and intra-organisational risk communication schemes. In addition, the practice of due diligence is not fully integrated into supplier identification and evaluation procedures. Furthermore, integrative risks, meaning the spread and amplification of risks upstream and downstream of the supply chain, have not yet been managed adequately. We also found that most companies conduct only very basic supplier segmentation. Finally, we observed that in many organisations there is a lack of collaborative and integrated intra-organisational risk communication schemes which can smooth the information and communication flows within and/or across different divisions or business functions.

As an important part of supply chain management systems, we advocate that a holistic and integrative approach to multi-tier supply chain risk management is no longer just an option, but is recognised as being decisive as globalisation, outsourcing and offshoring stretch the supply chain to its limit. The significant advantage of multi-tier visibility and collaboration is that it enables manufacturers to synchronise planning and coordinate execution activities based on information from all relevant stakeholders along the chain as a way of efficiently managing supply chain risks or disruptions.

The strategies and approaches for companies to avoid or reduce multi-tier supply chain risks vary. There are various factors which contribute to these differences. In spite of the complexity of multi-tier supply chain risk management, there are a growing number of successful examples that demonstrate its feasibility in practice. Current technologies such as radio-frequency identification, enterprise resource planning and general packet radio service will become important tools for supply chain network management (Tang, 2006b; Vanany et al., 2009), and future technologies are expected to make a big impact on visibility and traceability of supply chain networks (Ghadge et al., 2012).

Based on both empirical and scientific research, we have introduced four conceptual models to help companies to avoid supply chain risks and to seize potential opportunities. Firstly, the Three-Circle Model helps managers to identify the risks of a multi-tier supply chain partner. This model can be applied in both industries, but it is more applicable for the automotive industry where we have found that there is a stronger tendency in supply chain risk management to target only the first-tier supplier.

Secondly, the Risk Portrait of the Multi-Tier Supply Chain Partner Model increases the risk visibility and comparability of the selected multi-tier supplier. This is relevant to both of the industries studied.

Thirdly, the Multi-Tier Supply Chain Risk Management Circle Model treats the risk management process as a dynamic system. This model concentrates on integrating the re-evaluation of residual risk into supply chain risk management. This model can be applied in both studied industries.

Next, the quantitative approach to assessing multi-tier supply chain risks includes five basic steps, namely, prioritisation of supply chain risk by using tools such as Risk Mapping; quantification of the risk impact; modelling joint risk factor dynamics; calculating risk probability distribution; and aggregation of supply chain risks.

In addition, we argue that in the risk management process an efficient balance between IT systems, leadership and communication systems should be achieved.

Last but not least, there exists no simple solution for managing multi-tier supply chain risks. And there is no simple way to imitate the best supply chain. How supply chain operation and risk should be managed relies on internal corporate factors such as corporate strategy, core competitiveness and corporate resources, as well as external environment factors such as competition and regulation. The evidence seems compelling: only an appropriate supply chain management scheme can enable a company to reach a balanced set of metrics that are aligned with the ultimate corporate goal.

6 List of Figures and Tables

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