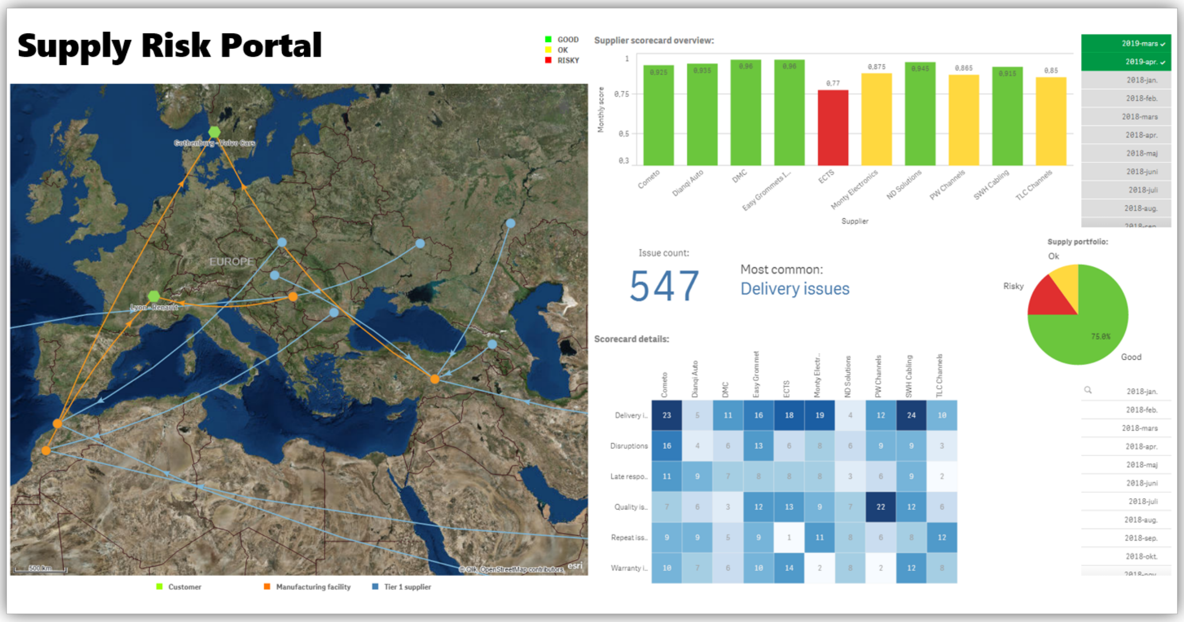

Managing and mitigating risk in technology supply chains

A case study on global auto parts manufacturer Aptiv

Master's Thesis in the Supply Chain Management Master's Programme

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Gothenburg, Sweden 2019
Report No. E2019:012

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Cover: Supply risk dashboard developed by the authors as a proof-of-concept visual reporting mechanism.

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Abstract

Purpose - This research aims to identify key enablers for proactive supply risk management within technology supply chains. Primarily by mapping out current supply risk areas, expected future risk areas and by conducting a comparative benchmark of how different manufacturing technology companies work with supply risk management.

Scope / Delimitations - The scope includes mapping the case company Aptiv's current supplier risk management processes by interviewing representatives from multiple business functions on a local and centralized level. Moreover, data was retrieved through interviews with managers from six other technology manufacturing companies and with researchers from academia.

Research questions - The study aims to answer the following research questions: (1) Which are the most critical risk areas experienced in technology supply chains today? (2) Which risk areas are most likely to be important in the future for technology supply chains? (3) What risk indicators can be used to assess supply side risks? (4) What are key strategies for proactive supply risk management in the future?

Results - It was found that many of the interviewed companies are experiencing similar risks within their supply chains - with emphasis on supply availability, geopolitical uncertainty, reduced Time-To-Market requirements and the inclusion of emerging risks such as resource scarcity and cyber security. Moreover, it was found that many companies work with supply risk management in a highly traditional and reactive manner - with extensive use of manual spreadsheets for conducting risk assessments. However, two out of the six interviewed companies were found to have started investing in emerging risk management technologies, such as geo-analytics platforms and source code management systems. These type of systems are presenting opportunities for earlier risk identification and proactive risk mitigation actions - however, it was found that early adopters in industry are scare due to difficulties proving the systems' return on investment.

Conclusion - Working proactively with supply chain risk management was identified as highly sought for by industry experts, but difficult to implement in practice. More so due to the fact that the supply side risks of today will not be the same as the risks of tomorrow. This research has hence narrowed down three focus areas for becoming better at proactive supply risk management in the future: (1) Supplier development and strategic partnerships; (2) Early risk indicator analysis and governance; and (3) Transitioning to more technically advanced decision support systems.

Keywords: supply chain, proactive risk management, risk analysis, risk indicators, risk monitoring

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Erik Almblad & Tobias Stenshagen
Gothenburg, June 2019

Nomenclature

$3BL$	Triple Bottom Line
$3PL$	Third Part Logistics
$ADAS$	Advanced Driver Assistance System
AI	Artificial Intelligence
API	Application Programming Interface
$APQP$	Advanced Product Quality Planning
AQE	Advanced Quality Engineer
BI	Business Intelligence
BIA	Business Impact Analysis
BIV	Business Interruption Value
BOM	Bill Of Materials
BRT	Business Recovery Time
CSR	Corporate Social Responsibility
$EBIT$	Earnings Before Interest and Taxes
ECG	Engineered Components Group
EDS	Electrical Distribution Systems
ERA	Environmental Risk Assessment
$ERMET$	Ericsson Risk Management Evaluation Tool
$FMEA$	Failure Mode Effect Analysis
$IATF$	International Automotive Task Force
IoT	Internet of Things
IP	Intellectual Property
ISO	International Organization of Standardization
KPI	Key Performance Indicator

LOB	Line-Of-Business
MOQ	Minimum Order Quantity
MRD	Material Requirement Date
OEM	Original Equipment Manufacturer
PC	Problem Case
PPAP	Production Part Approval Process
RFQ	Request For Quotation
ROI	Return On Investment
SCM	Supply Chain Management
SCRM	Supply Chain Risk Management
SQE	Supplier Quality Engineer
TTM	Time-To-Market
TTR	Time-To-Recover
TTS	Time-To-Survive

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1

Introduction

This introductory chapter describes why supply chain risk management has received a lot of increased attention in recent years, as well as illustrates how supply chain disruptions have impacted companies in the past. Additionally, it elaborates on why supply risk is particularly important in technology and automotive supply chains and what drives this increased focus. Lastly, it presents how sustainability and risk management correlate by looking at a selection of scandals in recent years.

1.1 Disruptive supply chains

One of the most prominent issues facing supply chain managers today is how to effectively deal with the vast amount of potential disruptions that can affect the complicated supply networks characterizing modern enterprises (Kırılmaz & Erol, 2017; Mital, Del Giudice, & Papa, 2018; Blackhurst, Scheibe, & Johnson, 2008). Although firms have always faced the risk of supply chain disruptions, the attention that managing and mitigating supply risk have received in recent years has increased dramatically. Four underlying developments are driving this change: increased supply chain complexity due to increased globalization, increased level of outsourcing and single sourcing, and the increased focus on removing slack from supply chains using strategies such as postponement and just-in-time. (Gurnani, Mehrotra, & Ray, 2012). While many of these strategies have improved operational performance, they have also made supply chains more prone to disruptions (Olson L., 2014; Thun & Hoenig, 2011; Gurnani et al., 2012).

The focus on managing supply chain disruptions has increased in recent years partly due to several costly and highly-publicized incidents. Such incidents include for example Mattel's recall of 21 million toys in 2007 due to safety issues (Choi & Lin, 2009b, 2009a); Philips microchip plant fire in Albuquerque 2000, resulting in an estimated $400 million loss in potential revenue for Ericsson (Chopra, Reinhardt, & Mohan, 2007); and Boeing's unexpected worldwide grounding of the 787 Dreamliner due to several fires that started in the airplane's batteries, resulting in an estimated revenue loss of $2.6 billion (Tang, Zimmerman, & Nelson, 2009; Kotha & Srikanth, 2013).

Supply chain risk is a phenomenon that can never be fully eliminated. It does however call for new and improved ways of managing, monitoring and mitigating high-impact risks in order to minimize the impact should a disruptive event occur.

1.2 Risks in technology supply chains

In technology supply chains in particular (i.e. electronics, automotive, telecom and similar) risk management is becoming increasingly important (Mital et al., 2018; Islamoglu, Ryu, & Moon, 2014; Gurnani et al., 2012; Wu & Weng, 2010). Traditional risk management strategies like utilizing buffer inventories and dual-sourcing is often not an option in today's competitive environment with constant margin pressure and just-in-time strategies (Mital et al., 2018). Additionally, new technologies are being introduced at a rapid pace forcing companies to partner with new suppliers and sometimes requiring a fundamental shift of core competencies (Cornet et al., 2019).

Increased product complexity and reduced time-to-market is also very much apparent, particularly in the automotive industry, calling for companies to expand their supplier portfolio by partnering with new suppliers specializing on a specific technology (Cornet et al., 2019).

Consequences for selecting a specific supplier are normally detected at a very late stage and are thus difficult to plan for, which calls for a more proactive approach for managing supply risk (Geraint, 2015). High tech companies can not risk entering the market too late, or risk substantial loss of market share with a high alternative cost. As illustrated more than two decades ago by Christensen (1997) in his renowned book *'The innovator's dilemma'* by looking at several instances where large firms fell behind their smaller competition, such as IBM losing significant market share failing to foresee the demand for 1.5-inch hard disk drives and Kodak failing to foresee the impact digital cameras would have on the market. Companies today are faced with this dilemma to an even greater extent due to more and more disruptive technologies being introduced. Moreover, corporate managers are forced to cope with increased supply side risk as well.

In summary, technology supply chains are constantly faced with the risk of disruptive technologies. This phenomenon has received significant attention throughout the 21st century in both academia, media as well as from corporate managers. What has received less attention however, but is gaining ground quickly, is the implications this has with regard to supply chain risk. Thus calling for additional research within the area, forming the basis of this study.

1.3 Sustainability and risk management

In order to conceptualize how sustainability and risk management correlate, a clear definition of sustainability is required. Giannakis and Papadopoulos (2016) expands upon a study by Krysiak (2009) and defines sustainability as:

> *"... the degree to which present decisions of organizations impact on the future situation of the natural environment, societies and business viability."* (Giannakis & Papadopoulos, 2016, p.455)

Further elaborating that the growing consumer awareness surrounding sustainability strategies that consider the effects on the triple bottom line (people, planet, profit) (Elkington, 1998), combined with the development of improved sustainability metrics for working conditions, accidents, carbon footprint and corruption indices, are increasingly forcing companies to take these costs and associated risks into account (Giannakis & Papadopoulos, 2016). Implying that sustainability strategies and supply risk management can never be mutually exclusive, but rather are means toward the same goal.

Some sustainability scandals in recent years include the 2013 European supermarkets horse meat scandal (Madichie & Yamoah, 2017); the Rana Plaza collapse in 2013 resulting in more than 1000 deaths and 2500 injuries (Jacobs & Singhal, 2017); and Apple's 2010 working conditions scandal at their Chinese manufacturing sites (Brian Merchant, 2017).

As illustrated by the aforementioned scandals, supply chain risk management is not limited to the reduction of and decreased vulnerability to disruptive events, but rather includes a much wider scope including mitigating risks that will have a negative impact on the triple bottom line (3BL)(Elkington, 1998). Companies simply can't risk being subject to this kind of events. Increasingly so due to the fact that social media and intensive media coverage tend to spread the word quickly, oftentimes with immediate and severe loss of corporate goodwill (Veit, Lambrechts, Quintens, & Semeijn, 2018).

2

Scope

This section defines the scope of the project by formulating a purpose, a set of research questions to be answered, what the study aims to deliver as well as outlines the delimitations of the project. Lastly, an overview of the report disposition is provided for outlining the objective of each chapter.

2.1 Purpose and research questions

The purpose of this study is to identify key strategies for proactive supply risk management within technology supply chains. Primarily by mapping out current supply risk areas, expected future risk areas and by conducting a comparative benchmark of how different manufacturing technology companies work with supply risk management. Conclusions are to be made about what risk management methodologies are best suited for managing supplier risk in technology supply chains in particular. To achieve this purpose, the following research questions were formulated:

1. Which are the most critical risk areas experienced in technology supply chains today?
2. Which risk areas are most likely to be important in the future for technology supply chains?
3. What risk indicators can be used to assess supply side risks?
4. What are key strategies for proactive supply risk management?

The first research question aims to explore which risk areas are most prominent in technology supply chains today. Managing and monitoring these risks is of particular importance in order to minimize the costs incurred when a disruption occurs. The second research questions aims to take this a step further by looking at what risk areas are most likely to be important in the future. As the technology industry is undergoing a paradigm shift with entirely new business models focused on servitization, IoT and increased product complexity, the risks are also expected to change. The third research question aims to evaluate which risk indicators can be most suitably used by supply chain and purchasing managers when assessing supply chain risk in practice. Research question four aims to identify key strategies for managing and mitigating supply side risks more proactively - i.e. before occurrence - as opposed to reactive - i.e. after occurrence. This is becoming increasingly possible with the introduction of new tools and techniques such as AI, machine learning and data analytics. Literature and freely available practical implementations of how to utilize these tools for improved supply chain risk management is lacking, calling for additional research within the field.

2.2 Project deliverables

The project deliverables are twofold and can be grouped into two categories: short-term and long-term suggestions for improved supply chain risk management.

Short-term

The study aims to deliver a set of short-term suggestions for how to work more effectively with supply chain risk management based on the systems and processes used today. The suggestions aim to be:

- Practical and not overly burdensome.
- Quick to implement and easy to maintain.
- Provide early warning signals for potential problems and risks in the supply base.

Additionally, the study aims to map out and categorize which risk areas are most prominent today in technology supply chains. These are risks subject to the industry as a whole, and not necessarily specific to the focal company.

Long-term

From a long-term perspective, the study aims to identify which supply side risk areas are expected to be particularly important in the future based on trends within the industry.

Based on this, suggestions for how to strategically work with supply chain risk management are to be proposed. These suggestions are to be based on challenges and limitations of risk management practices used in industry today.

Proof-of-concept supply risk dashboard

Lastly, the authors have developed a proof-of-concept tool for visualizing how supply side risk may be managed and monitored in the future. This is intended to showcase a system that potentially could replace the extensive use of spreadsheets and manual labour that is present in industry today.

The proposed system was developed in QlikSense, using the Qlik Associative Engine. The dashboard is based on empirical data gathered throughout the study, such as through interviews and from studying internal documents, procedures and risk indicators that are assessed at the focal company today.

2.3 Delimitations

The study is focused on supply chain risk management within technology industries, however the empirical data was retrieved primarily from respondents within automotive. Although six external technology manufacturing companies were interviewed, the basis of the empirical background comes from the interviewed respondents at the focal company Aptiv and through review of internal documents and procedures.

The supply side risk areas (RQ1 & RQ2) that were identified to be exclusive to the automotive industry were not prioritized, although a selection are presented in this report.

Focus of the study is to evaluate risks that are applicable to technology supply chains in general and not unique to automotive.

The proposed risk assessment framework used to answer RQ3 is based primarily on risk factors assessed by Aptiv today, with the inclusion of additional risk factors and indicators used by external companies. Utilizing this framework in a non-automotive context may require additional risk factors and metrics to assess.

The analysis of the various tools that were identified as enablers for improved proactive supply risk management (RQ4) is general and will be applicable to other organizations. However, the depth and detail of the different tool's description is limited and would require additional research.

2.4 Report disposition

Table 2.1 presents an overview of the report's respective chapters' objective. This aims to assist the reader in finding the chapter of interest more quickly.

Table 2.1: Report disposition overview.

Chapter	**Objective**
Chapter 1: Introduction	Introduces supply chain risk management and why it is of particular importance within the technology industry. This is intended to provide some background information to the reader regarding the relevance of the study's purpose and research questions.
Chapter 2: Scope	Formulates the study's purpose, a set of research questions, delimitations and outlines what the project aims to deliver.
Chapter 3: Research method	Provides an overview of the research method used to conduct the study, including data gathering, sampling methods and data analysis. Interview templates are provided.
Chapter 4: Literature review	Outlines the theoretical background by introducing six separate focus areas: (1) Supply Chain Risk Management frameworks and tools, (2) Disruptive events in the past, (3) Risk categorization, (4) Supplier risk and performance indicators, (5) Future of the automotive industry and (6) Risk management trends.
Chapter 5: Case description	Provides background information on the case company Aptiv and describes the primary processes deployed for supply chain risk management today.
Chapter 6: Empirical findings	Empirical data from interviews with managers at the focal firm and from six external companies is presented. The chapter consists of multiple tables containing primary takeaways from each respondent.
Chapter 7: Analysis and Discussion	Elaborates on the empirical data and presents answers to each of the study's research questions.
Chapter 8: Conclusion	Summarizes the main findings of the study, presents the recommendations and suggests areas for additional research.

3

Research Method

This chapter starts off by providing an overview of the study's research method. Secondly it explains what methods were used for data collection and data analysis. Thirdly, each of the phases are described in more depth before concluding the chapter with two sections covering the research's limitations and trustworthiness.

3.1 Overview

The research method consists of four distinct phases that were executed sequentially. A brief overview of each of the four phases is provided below, summarizing their key steps and their respective purpose.

Phase one: Aptiv case study and literature review
During Phase one an internal status analysis of Aptiv's current risk management procedures was performed. Primarily by conducting semi-structured interviews with respondents from business functions such as purchasing, supplier quality, program management and engineering. In parallel to the status analysis, a literature review was conducted for gathering relevant theoretical knowledge within the field. This phase aimed to gather insights that would then be cross-referenced with input retrieved when interviewing the external companies.

Phase two: External study
In the second phase the focus was on identifying how other technology companies work with supply chain risk management and what risk areas they considered particularly important. Moreover, of particular interest was to identify supply risks related to sustainability and the 3BL. This was done by interviewing managers from six external manufacturing technology companies and a researcher from academia. This phase resulted in empirical findings that when combined with insights from the Aptiv case study aimed to increase the validity of the study.

Phase three: Comparative benchmark analysis
Once supply chain risk management (SCRM) procedures and perceived risk areas had been identified both internally (phase one), and externally (phase two), the next step was to perform a comparative benchmark. During the benchmark, the authors utilized a categorizing and interpretive approach for identifying: (1) Overlapping risk areas perceived by multiple respondents; (2) Common methods for risk mitigation; and (3) Potential risk management tools for improved proactive risk management.

Phase four: Suggest improvements
Based on insights from the aforementioned benchmark, phase four consisted of suggesting general recommendations for improved supply chain risk management within the technology industry. This included practical suggestions, key enablers and key strategies for improved proactive supply risk management.

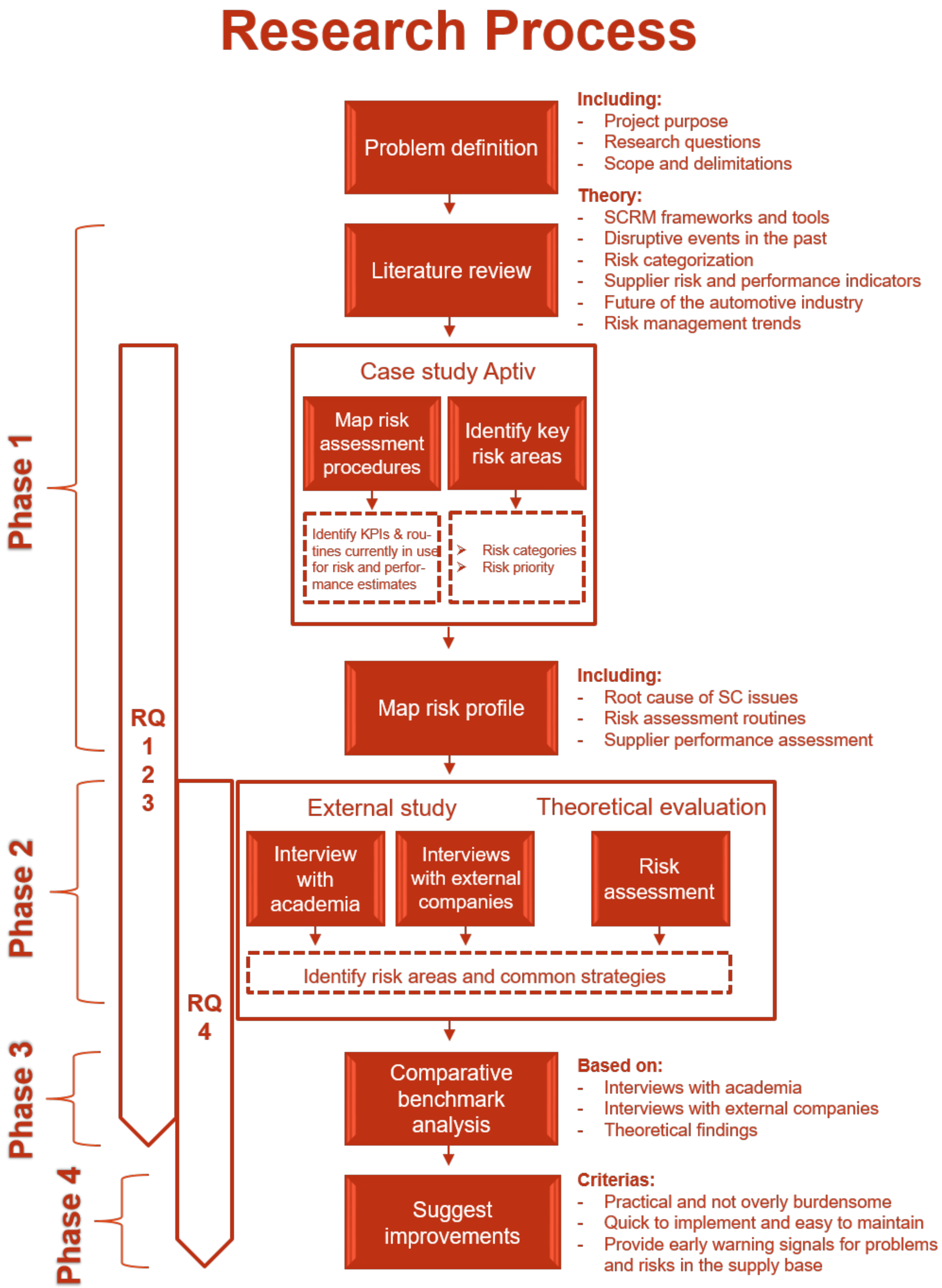


Figure 3.1: Overview of the research method used to conduct the study.

3.2 Data gathering and analysis

The process of gathering data consisted of two major steps. The first being conducting semi-structured interviews with representatives from the focal company, external companies and academia. A semi-structured approach was chosen as it allows participants to present their individual understandings and experiences (King & Horrocks, 2010), without limiting them to a constrained data set. The secondary step for data gathering was based on conducting a literature review of case studies, academic research papers and textbooks within supply chain risk management - as described in more depth in section 3.3.1.

3.2.1 Hermeneutic spiral

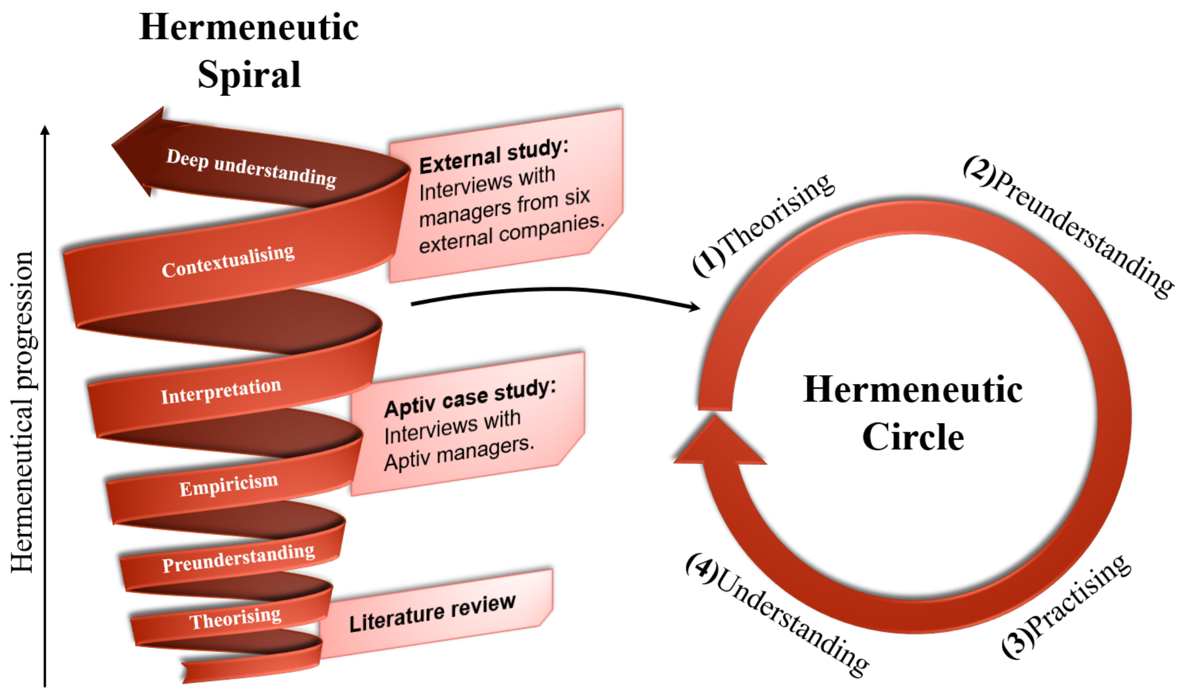


Figure 3.2: Illustration of the Hermeneutic Spiral and Hermeneutic Circle.

The analysis method used to analyze the qualitative data gathered from the interview respondents resembled the *Hermeneutic Spiral*, originally proposed and developed by Osborne (1991). The *Hermeneutic Spiral* is an extension of Martin Heidegger's original work on the *Hermeneutic Circle* (1927), describing the upward and iterative process of moving from an earlier preunderstanding to a deeper understanding of a topic as more and more empirical data is gathered.

In practice, the spiral consist of multiple iterations of the *Hermeneutic Circle*, where initially the understanding is based primarily on theory, on which a preunderstanding is built, to then be tested in practice as empirical data is gathered through interviews, which ultimately creates a deeper understanding of the topic. As more and more interviews are conducted, the interviewers widen their understanding, make more accurate interpretations, improves their contextualizing and finally it results in a deeper understanding of the field of study.

3.2.2 Collection of primary data

The primary data was gathered through interviews with Aptiv employees, six external technology companies and one researcher. The interviews were used as the foundation for the empirical evidence as they allowed for an in-dept exploration of risk assessment processes from multiple perspectives (Easterby-Smith, Thorpe, & Jackson, 2015). Table 3.1 illustrates what primary data were used to answer each research question.

Table 3.1: The empirical evidence's relevance for answering the study's research questions.

Research question	**Empirical evidence**	**Theoretical evidence**
RQ1: *Which are the most critical risk areas experienced in technology supply chains today?*	- Interviews with Aptiv managers from departments including: purchasing, program management, supplier quality and engineering. - Interviews with managers from external companies from functions such as strategic purchasing, supply chain management and project management. - Risk identification workshop with a cross-functional focus group with Aptiv managers (see Appendix A). - Interview with academia.	- Literature on risk areas and disruptive events that have occurred in technology supply chains in the past. - Information on risk categorization within technology and automotive supply chains and what risk categories/areas are most commonly used.
RQ2: *Which risk areas are most likely to be important in the future for technology supply chains?*	- Interviews with Aptiv managers. - Interviews with managers from six external manufacturing technology companies. - Interview with academia.	- Literature elaborating on the future developments of the automotive industry and its transition to an increasingly technology intensive industry.
RQ3: *What risk indicators can be used to assess supply side risks?*	- Review of internal documentation and procedures at Aptiv. - Interviews with supplier quality and advanced quality engineers at Aptiv. - Risk assessment worksheet. - Supplier scorecards.	- Frameworks/models on how companies work with managing risk today, what intermediate steps and specific indicators are being taken into account. - Literature on the most common risk indicators used in the automotive and electronics industry.
RQ4: *What are key enablers for proactive supply risk management in the future?*	- Interviews with managers from external companies from functions such as strategic purchasing, supply chain management and project management. - Interviews with program management at Aptiv. - Interviews with academia.	- Literature of the future development of risk management. - Literature of future tools utilizing new technologies to enable more proactive risk management.

3.3 Phase 1: Aptiv case study and literature review

Phase 1 consisted of two distinct steps, an empirical status analysis performed at the case company Aptiv combined with a parallel literature review. Each of these steps, what they included, how they where performed, what data was gathered and how they contributed to answering each research question is outlined in this section.

3.3.1 Literature review

The literature review is divided into six areas: (1) Supply chain risk management frameworks and tools, (2) Disruptive events in the past, (3) Risk categorization, (4) Supplier risk and performance indicators, (5) Future of the automotive industry and (6) Risk management trends. These areas provided a theoretical framework used to gather the right information during the qualitative studies of supply chain risk management processes at Aptiv and the other studied companies. The framework provided by the literature review also functioned as a springboard when analyzing the potential improvement strategies later in the project.

The literature review was based on academic research, case studies, consulting reports and textbooks, available primarily through electronic databases such as Summon and Google Scholar. Parts of the literature were retrieved directly from Chalmers' library.

3.3.2 Aptiv case study

An empirical status analysis was performed to map current risk management processes and the most critical risks facing Aptiv's supply chain. Firstly, semi-structured interviews were conducted with respondents from purchasing and supplier quality departments from Aptiv Gothenburg and from Aptiv EMEA. The interviews were conducted face-to-face with respondents based in Gothenburg, and via Skype with respondents from Aptiv EMEA - with an average length of 60-90 minutes. After an initial round of interviews, a cross-functional workshop was conducted with Aptiv managers with the purpose of identifying additional risk areas and for performing a risk prioritization.

Respondent sampling method

The potential respondents for the Aptiv case study were limited in numbers due to the specific knowledge required to provide valuable insights. Potential respondents needed to have broad experience from sourcing activities, supplier auditing or supply chain management activities within Aptiv's organization.

The employees that possess the knowledge required were primarily situated in other countries. To enable contact with these potential respondents, the snowball sampling method was used. The snowball sampling took root in the corporate representative for this project who had professional connections to potential respondents with required experiences. The snowball sampling method is suitable when respondents with required expertise are difficult to find and/or get hold of (Easterby-Smith et al., 2015), and hence snowball sampling was deemed a suitable sampling method for the case study.

Table 3.2: Selection of respondents

Interview respondent	**Company**
Program manager	Aptiv Gothenburg
Program purchasing manager	Aptiv Gothenburg
Regional category manager	Aptiv EMEA
Regional category manager	Aptiv EMEA
Engineering manager	Aptiv EMEA
Engineering manager	Aptiv EMEA
Advanced quality engineer (AQE)	Aptiv EMEA
Supply quality engineer (SQE)	Aptiv EMEA
Quality manager	Aptiv Gothenburg
Group leader for technical project managers	Aptiv Gothenburg

The selection of respondents were made in order to gather representative knowledge within the three selected focus areas: (1) *Risk assessment procedures*, (2) *Key risk areas* and (3) *Issues in current supply chain.*

Table 3.3: Purpose of interviews in the Aptiv case study

Focus area	**Title of respondent**	**Purpose of interview**
Risk assessment procedures	Advanced Quality Engineer	- Insights on supplier risk assessment worksheets
	Supplier Quality Engineer	- Insights on supplier risk assessment worksheets
	Purchasing manager	- Insights on supplier risk assessment processes
Key risk areas	Program manager	- Most crucial risk areas in his/her program and potential improvement strategies
	Purchasing manager	- Most crucial risk areas in his/her purchasing category and potential improvement strategies
	Project steering manager	- Most crucial risk areas in his/her project and potential improvement strategies
Issues in current supply chain	Engineering manager	- Supplier issues affecting their product development
	Purchasing manager	- Supplier issues affecting the category purchasing
	Program manager	- Supplier issues affecting the company's competitiveness
	Category manager	- Supplier issues affecting the company's competitiveness

Interview template

The interview templates differed for the three separate focus areas, due to the differences in the desired outcome. An overview of the interview template used for each respective focus area is presented in Table 3.7.

Table 3.4: Interview templates for the three focus areas

Focus area	Interview template
Risk assessment procedures	**Main topics:** - Sourcing process used today - Risk assessment processes and worksheets - Supplier scorecards - Sustainable supply chain risk management **Specific questions:** - How are supply risk assessments performed today? - When do you conduct the assessments? And how often? - Who is responsible for different assessment stages? - Is input from other departments considered? - How are risk factors weighted? - How do you follow up / audit selected suppliers? - How is the supplier selection affected by the 3BL?
Key risk areas	**Questions:** - What are the risk areas faced within Aptiv's supply chain today? - Are there any risk areas related to sustainable development? - Are there any risk areas that you consider particularly important? - Any ideas on how to improve governance, control and/or mitigation strategies for these risk areas?
Issues in current SC	**Questions:** - What are the major sourcing issues your department/category is facing? - Are there any risk indicators that could have prevented these issues? - Other ideas on how to improve governance, control and/or mitigation strategies for these issues?

Whenever possible, additional verification inquiries was sent out to the interview respondents at Aptiv. This to to verify the interviewer's understanding of the focus areas discussed during the interview.

Risk identification workshop with a cross-functional focus group

Part of the Aptiv case study included conducting a risk identification workshop with a cross-functional focus group. The purpose of the workshop was to identify additional supply risk areas, prioritize identified risks, and lastly to discuss potential control and mitigation strategies. The result of which, combined with individual interviews, formed a foundation for answering RQ1 *'Which are the most critical risk areas experienced in technology supply chains today?'*.

The focus group consisted of participants from various business functions, including program management, engineering and purchasing department. An overview of the workshop agenda is outlined below:

1. First the participants were asked to individually identify as many risk areas as possible.

2. Secondly, participants were asked to prioritize a limited set of their own risks and share it with the others.

3. Thirdly, all participants were asked to assign a priority to the group's selected risk areas.

4. Lastly, a set of potential mitigation strategies were discussed for the selected high priority risks.

A more detailed description of the workshop agenda and the exact outline can be found in Appendix A.

3.4 Phase 2: External study

In order to collect insights on how risk management in technology supply chains is accomplished at other organizations, data was collected through semi-structured interviews with managers from six other manufacturing companies.

The focus during the external interviews was to map other large companies supply chain risk management processes and their primary supply chain risk areas. Furthermore, their usage of new risk management techniques and tools were to be mapped. The interviews were performed using a semi-structured approach to enable the respondents to speak freely within a relatively narrow topic prepared beforehand depending on the interviewees professional role and background.

In addition to the interviews with external companies, an interview was conducted with a representative from academia. The respondent for this interview was an postdoctoral researcher at Chalmers University of Technology with practical and academic experience from supply chain risk management. The aim being to identify trends in risk management from a research based perspective, such as the introduction of new SCRM tools and risk assessment procedures.

At this point the authors had developed a better understanding supply risk management within the technology industry and a new iteration of the hermeneutic spiral was initiated. Hence, in parallel to the external study new literature and theories was studied and added to the literature review in order to further increase the understanding to the subject.

Respondent sampling method

The respondent sampling method used for initiating contact with external companies was twofold. Firstly, just like throughout the Aptiv case study, it was partly based on a snowball sampling procedure originating in an upper management Aptiv representative who provided additional contact details to external companies. Secondly, external interviewee candidates were contacted by email.

Regarding the respondents for *'Interviews with academia'*, contact was initiated with professors and researchers with knowledge and experience from supply chain risk management that were employed by Chalmers University of Technology.

Table 3.5: Selection of external study respondents

Interview respondent	**Company**
Strategic purchasing manager	Networking and telecommunication manufacturer
Project manager	Space technology manufacturer
Supply chain manager	Electrical equipment manufacturer
Manufacturing director	MedTech company
Risk manager	Technology manufacturing company
Purchasing & supply chain manager	Climate solutions manufacturer
Postdoctoral researcher	Chalmers University of Technology

Table 3.6: Purpose of interviews in the external study

Background	**Area of expertise / Title**	**Purpose of interviews**
Academia	- Postdoctoral researcher in logistics and sustainable SCM	Insights on risk management trends and modern risk assessment tools suggested by recent research.
Industry	- Strategic purchasing manager - Project manager - Supply chain manager - Manufacturing director - Risk manager - Purchasing & supply chain manager	Map the companies' risk management processes, primary risk areas and usage of new technologies in risk management.

Interview template

The purpose of the interviews with academia and industry was to evaluate what are current trends and common industry practices for supply chain risk management at companies operating in technology industries. Furthermore, the interviews aimed to map out what primary supply side risks different companies are facing. To achieve this purpose, the interview template in Table 3.7 was derived by the authors, although modified accordingly to match each respondents individual role and background.

Table 3.7: Interview templates for the external study

Background	Interview template
Academia	**Main topics:** - Recent development in risk management - Introduction of new tools and techniques - Risk areas related to sustainable development
Industry	**Main topics:** - Current methods for assessing supply risk - Primary supply risk areas - Strategies for mitigating risk - Sustainability and its relation to risk management - New technologies for supply side risk assessments

3.5 Phase 3: Comparative benchmark analysis

Phase 3 consisted of conducting a comparative benchmark where different companies' approaches for working with supply chain risk management were compared and commonalities were derived. A benchmark is a method used to identify improvement potential in one's own business by studying other companies business practices. The companies studied while performing a benchmark are often the largest competitors or other companies with similar business practices as one's own business (Merriam Webster, 2019).

During the benchmark, the authors utilized a categorizing and interpretive approach for identifying: (1) Overlapping risk areas perceived by multiple respondents; (2) Common methods for risk mitigation; and (3) Potential risk management tools for improved proactive risk management. Moreover, insights gathered from the interview with academia and from the literature review was reviewed and incorporated into the benchmark analysis. The expected outcome was to answer the study's four respective research questions and to provide a foundation on which improvement potential and practical suggestions were to be derived and delivered to the case company.

3.6 Phase 4: Suggest improvements

In the final phase of the study, the authors aimed to propose suggestions and provide general recommendations for how supply chain risk can be managed more effectively and proactively in the future based on the research findings. This included practical suggestions, key enablers and key strategies for improved proactive supply risk management.

This phase was initiated once the interview rounds were completed, at which time the authors had iterated through multiple iterations of the hermeneutic circle. Insights had been gathered from multiple independent sources, both from studied literature and from interviews with external corporate managers, and each iteration improved the authors understanding of the field allowing for suggestions rooted both in literature and in industry.

The suggestions were required to be (1) Practical and not overly burdensome, (2) Quick to implement and easy to maintain and (3) Provide early warning signals for potential problems and risks in the supply base.

The development of the final suggestions was based on three primary inputs: (1) Aptiv's current risk assessment processes, (2) Theoretical evidence gathered throughout the literature review and (3) Insights gathered by interviewing external companies. Furthermore, the suggestions aimed to be as generic as possible, hoping to provide a basis on which other technology companies can learn from and expand upon when developing their own risk assessment procedures.

3.7 Research limitations

A notable limitation for the study is that detailed empirical data regarding supply chain risk management practices was only gathered from one company, i.e. the studied auto parts manufacturer. Although interviews were conducted with managers from external companies, the data retrieved were of a high-level nature. Exact metrics and evaluation criteria used for conducting risk assessments were not retrieved throughout the external study.

Moreover, due to the limited sample size of interviewed companies it is not possible to say that all major supply risk areas have been identified. If additional suppliers and OEMs had been interviewed, additional risks may have been identified. Although many of the risks can arguably be attributed to the industry as a whole, the sample size is too small to safely say that the identified risks are generally applicable.

Furthermore, a limited amount of interviews were conducted with managers from the focal company for mapping current risk management routines. Thereby it is possible that certain risk assessment steps were left out. However, this is only considered as a minor limitation as the interviewees had extensive knowledge within the field and intentionally described the most important steps.

3.8 Research trustworthiness

As with all qualitative research, there is no ground zero or single point of truth. As is the case in this study. The resulting recommendations for how to better conduct supply side risk assessments is heavily based on the empirical data gathered throughout the case study at the studied auto parts manufacturer. As the data was gathered using a snowball sampling procedure, approaching the problem fully objectively was not feasible.

As such, applying the recommendations within any of the many subcategories included within *technology industries* may require designated and unique metrics, unique risk indicators and specific tools in order to be effective. With that said, this research presents a comprehensive risk assessment framework that takes into account a majority of critical supply chain risk areas, and as such it can act as a basis on which additional metrics and risk factors can be added.

The qualitative data used in the study, gathered primarily via interviews, is subject to false interpretation by the authors. To minimize this, whenever possible, additional verification inquiries was sent out to the interview respondents to verify the interviewer's understanding.

4

Literature Review

The literature review is divided into six major areas: (1) Supply Chain Risk Management frameworks and tools, (2) Disruptive events in the past, (3) Supplier risk and performance indicators, (4) Risk categorization, (5) Future of the automotive industry and (6) Risk management trends. These areas are presented in separate sections throughout this chapter and provide a foundation on which the empirical research of supply chain risk management processes at Aptiv and the other studied companies have been evaluated and analyzed.

How the theoretical findings are relevant within the context of supply chain risk management is visualized in Figure 4.1. Although countless processes exist for how to manage supply chain risk, general consensus is reached amongst researchers about the four primary steps required (de Oliveira, Marins, Rocha, & Salomon, 2017), as is depicted in Figure 4.1. These steps include to: (1) Identify, (2) Evaluate, (3) Mitigate and (4) Monitor. The visualization acts as a reference point from which the reader can select what section to read.

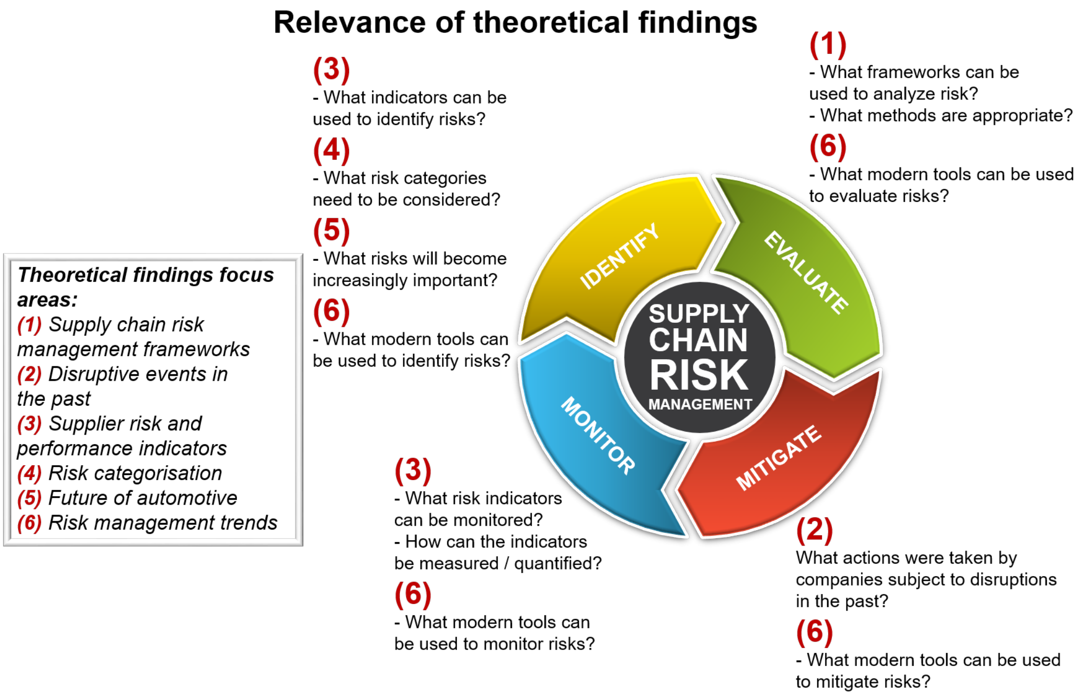
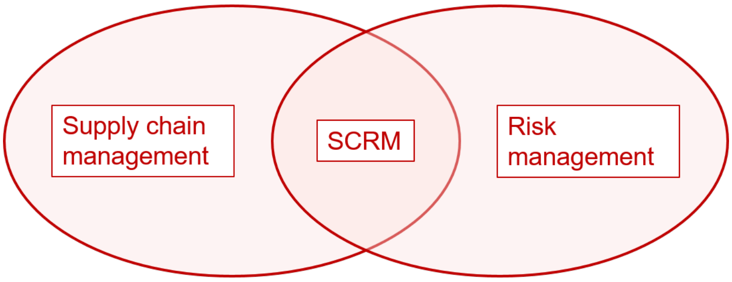


Figure 4.1: Theoretical findings relevance within the context of supply chain risk management.

4.1 Supply Chain Risk Management - Concepts and definitions

Supply chain risk management is described by Paulsson (2004) as the intersection between supply chain management and risk management, as illustrated in Figure 4.2. Supply chain management is in turn defined by Stanton (2018, Ch. 1 - Defining Supply Chain Management) as *'the planning and coordination of all of the people, processes, and technology involved in creating value for a company'*.

Figure 4.2: Illustration of the concept of supply chain risk management.

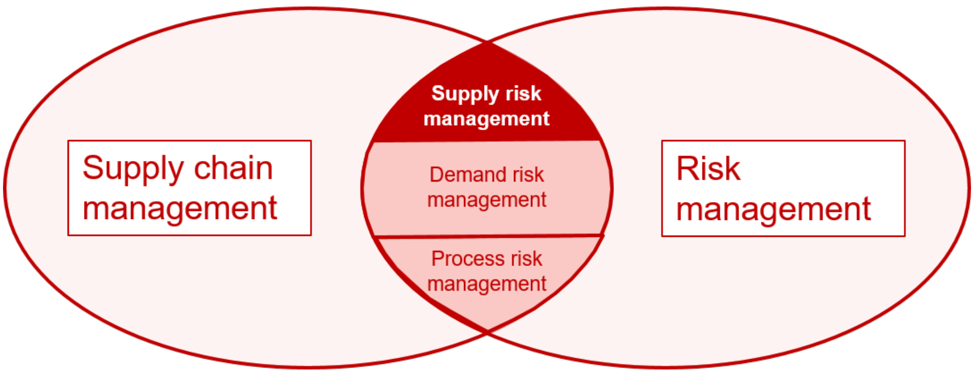


As defined by Paulsson (2004).

Risk management involves finding and controlling issues that may impact the performance of the company (Pritchard, 2014). Risk management is defined by Warner (2007, Ch. 3 - Determine) as: *"...a method of managing that concentrates on identifying and controlling the areas or events that have a potential of causing unwanted change..."*. The risk evaluation part of risk management is often performed by estimating probability of occurrence and the impact a disruption will have on the company should it occur (Khojasteh-Ghamari & Irohara, 2018).

According to the definitions of supply chain management and risk management mentioned above, supply chain risk management implicates a broader definition than the scope of this report. Hence, the focus of the literature review is limited to describing the risk management activities related to purchasing of components and raw materials from down-tier suppliers. This is described by Khojasteh-Ghamari and Irohara (2018) as *Supply risk management*, which excludes the areas described as *Demand risk management* and *Process risk management*. Demand risk management refers to risks originating from the customer side of the supply chain whereas process risk management refers to risks related to manufacturing. The definitions and their correlations are illustrated in Figure 4.3.

Figure 4.3: Illustration of the focus area for the literature review.



4.2 Supply Chain Risk Management - Frameworks and tools

This section is divided into four parts. In the first part, a generic framework for supply chain risk management including the most common risk management activities is presented. In the second and third part, two case studies of companies utilizing different approaches for supply chain risk management is described. In the fourth part, the six most commonly used risk assessment tools within the automotive industry are presented.

4.2.1 A generic supply chain risk management framework

The literature presents numerous supply chain risk management models. As described by de Oliveira et al. (2017) the different risk management models presented in literature consists of up to 13 different steps. Some of these steps can to varying degree be replaced by other similar steps proposed by other authors. Therefore, de Oliveira et al. (2017) identifies the four most common steps in supply chain risk management in their article *'The ISO 31000 standard in supply chain risk management'*. The four steps are described as: (1) risk identification, mentioned by 96 percent of the researchers, (2) risk evaluation, which was mentioned by 93 percent of the researchers within the field, (3) risk mitigation, mentioned by 100 percent, and (4) risk monitoring, mentioned by 67 percent.

These four steps form a generic risk management model (see Figure 4.4) consisting of the most common procedures in supply chain risk management. This four step approach is described in the remainder of this section.

Figure 4.4: A generic supply chain risk management framework.

*% of SCRM researchers that have included this, or a similar, step in their framework.

Standardized **Risk identification** models are scarce within companies (Simba, Niemann, Kotzé, & Agigi, 2017) and due to this, the creation of formal methods for risk identification can often help companies increase their supply chain risk management efficiency. As described by Scholten, Sharkey Scott, and Fynes (2014), Thun and Hoenig (2011) there are two main categories of methods to be used in risk identification: (1) proactive methods, used to identify risks prior to their occurrence, and (2) reactive methods, used to identify risks after they occur.

As described by Badurdeen et al. (2014), Bandaly, Satir, Kahyaoglu, and Shanker (2012), during the **risk evaluation** phase the different risks are often sorted into a hierarchy depending on their relative importance. Further stating that the importance of risks are to be evaluated in terms of their probability, frequency and potential impact on the company. The evaluation step normally consists of conducting various risk assessment methods, such as Business Impact Analysis (BIA), Cost/Benefit Analysis, Scenario Analysis, Environmental Risk Assessment and Failure Mode Effect Analysis (de Oliveira et al., 2017), all of which are described in section 4.2.4.

How to perform the **risk mitigation** activities depends on what categories of risks that the company is exposed to (Wieland, 2013; Kumar, J. Himes, & P. Kritzer, 2014). The two main categories of risk mitigation strategies are described by Wieland (2013), Kumar et al. (2014) as either redundant or flexible strategies. As described by Simba et al. (2017), two examples of redundant strategies are if you as a company are either purchasing excess inventories to be able to survive a disruption, or that you are using a centralized warehouse structure to even out demand fluctuations. The flexible strategy, on the other hand, does not require you as a company to carry excess stock, but instead requires a more flexible supplier network. Examples of strategies that will make a supply chain more flexible is multi-sourcing (having multiple suppliers for each component) and flexible distribution (having multiple third party logistics providers) (Simba et al., 2017). When choosing suitable risk mitigation strategies, factors such as cost, effectiveness and customer service needs to be considered (Kumar Sharma & Bhat, 2014).

Risk monitoring is the last step of the risk management approach described by Simba et al. (2017), and it is also the last of the four most common supply chain risk management steps described by de Oliveira et al. (2017). Risk monitoring is the process of auditing the efficiency of the risk mitigation strategies, as well as the process of improving the chosen risk mitigation strategies if the desired supply chain performance is not reached by previously chosen strategies (Tummala & Schoenherr, 2011).

4.2.2 Supply chain risk management framework based on Time-To-Recover and Time-To-Survive

Through a three year research engagement with Ford Motor Company performed by Simchi-Levi et al. (2015), the concepts of *Time-To-Recover* (TTR) and *Time-To-Survive* (TTS) were developed. These metrics aim to provide a complementary approach of how to holistically manage risks within a supply chain without having to perform unique risk assessments for each and every potential disruption. Simchi-Levi et al. (2015, p.378) define *Time-To-Recover* as:

> *"...the time it takes for a node to recover to full functionality after a disruption."*

And respectively define *Time-To-Survive* as:

> *"...the maximum amount of time the system can function without performance loss if a particular node is disrupted."*

Given the complexity of Ford Motor Company's operations at the time of the research, with 50 manufacturing plants worldwide, more than 10 tiers of suppliers between itself and its raw materials and the fact that the first tier of suppliers alone amounted to more than 1400 companies spread out globally at more than 4400 manufacturing sites - Simchi-Levi et al. (2015) argue that predicting, quantifying and managing the risks in such a complicated supply network is difficult and too often result in suboptimally deployed countermeasures. Ford managers estimated that conducting a risk analysis for all of their 4400 Tier 1 suppliers would likely take two or three years, at which time the analysis would be obsolete (Simchi-Levi et al., 2015).

Simchi-Levi et al. (2015) further argues that traditional risk assessment methods focused on identifying the probability and magnitude of disruptions are suboptimal due to several reasons: (1) It's difficult and often impossible to accurately estimate the likelihood of a high-impact, low-probability event (Banks, 2005); (2) Managers tend to misallocate resources when facing low-probability events (Johnson, Hershey, Meszaros, & Kunreuther, 1993); (3) Managers tend to ignore risks regardless of their potential significance (March & Shapira, 1987); (4) Managers tend to distrust or disregard precise probability estimates (Kunreuther, 1976). Hence **TTR** and **TTS** were proposed, combined with a novel risk-exposure model focused on assessing the impact of a disruption regardless of its source.

In the proposed model, each supplier is represented as a node in a supply network. The model takes financial measures (e.g. unit profitability) and operational measures (in-transit and on-site inventory levels) as inputs, combined with TTR information approximated by the suppliers themselves (Simchi-Levi et al., 2015). The model then iterates over all nodes in the supply network and simulates a disruption for the duration of the node's TTR value and calculates the corresponding performance impact (PI) on Ford. Using linear programming, the model then reallocates existing inventory, redirects supply alternatives and idles downstream plants in order to minimize the performance impact. Supported performance measures to minimize include lost units of production, lost sales and lost profit margin (Simchi-Levi et al., 2015).

TTS was proposed as a compliment to TTR due to the supplier's ability to be overly optimistic when assessing its TTR. Claiming to have a lower TTR than the actual value makes a supplier more likely to win the business from Ford, causing Ford to underestimate the actual risk exposure. The associated TTS value of a specific node is generated using inventory levels and the availability of alternative sources of supply. The TTR value can then be compared with TTR, and two conclusions can be drawn:

1. If TTS far exceeds TTR, then a large change in TTR will have little impact on the firm's risk exposure.
2. If TTS is short, Ford needs to engage in detailed discussions with their suppliers about their TTRs.

The risk-exposure model was used by Ford's procurement staff as a decision support system in three ways:

> *"(1) strategically, to identify exposure to risk associated with parts and suppliers, effectively prioritize and allocate resources, segment suppliers, and develop mitigation strategies; (2) tactically, to track daily changes in risk exposure to alert procurement executives to changes in their risk position; and (3) operationally, to identify effective ways to allocate resources after a disruption." (Simchi-Levi et al., 2015, p.379)*

4.2.3 Supply chain risk management framework based on Business Interruption Value and Business Recovery Time

After what is known as *"The Albuquerque Accident"* in year 2000, where one of Ericsson's key suppliers of semiconductors was incapacitated due to a plant fire in Albuquerque, New Mexico, Ericsson decided to do a total redesign of their supply chain risk management processes (Norrman & Jansson, 2004). This section describes how Ericsson's processes looked prior to and after the event.

Prior to the event, risk management was handled by a separate corporate function at Ericsson, which was primarily dealing with insurance companies. The new risk management approach, initiated after the event, instead emphasizes cross functional teams and gathering input from multiple business functions (Norrman & Jansson, 2004). These functions include:

- A designated corporate risk management business unit
- The SCM and logistics function
- The purchasing function
- System business areas (product owners)

Representatives from each function make up what Ericsson calls a *'Risk Management Council'*, which is responsible for dividing responsibilities between the various functions as well as minimizing the overall risk exposure in the supply chain. Ericsson's risk management approach consist of four steps: (1) Risk identification, (2) Risk assessment, (3) Risk treatment and (4) Risk monitoring. In parallel, emphasis is put on incident handling and contingency planning, as depicted in Figure 4.5.

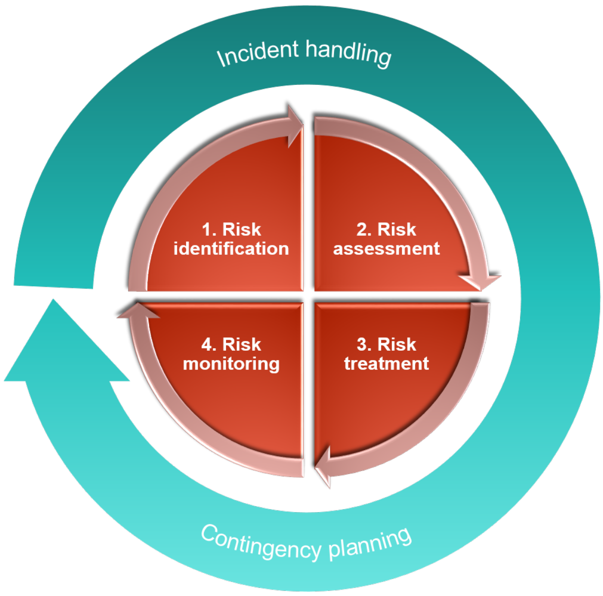


Figure 4.5: Ericsson's risk management approach after the *'Albuquerque accident'*.

Additionally, Ericsson proposed a novel approach for how to systematically analyze risk on a *'per component'* basis. The overall approach of this process is outlined in Figure 4.6, based on the description provided by Norrman and Jansson (2004).

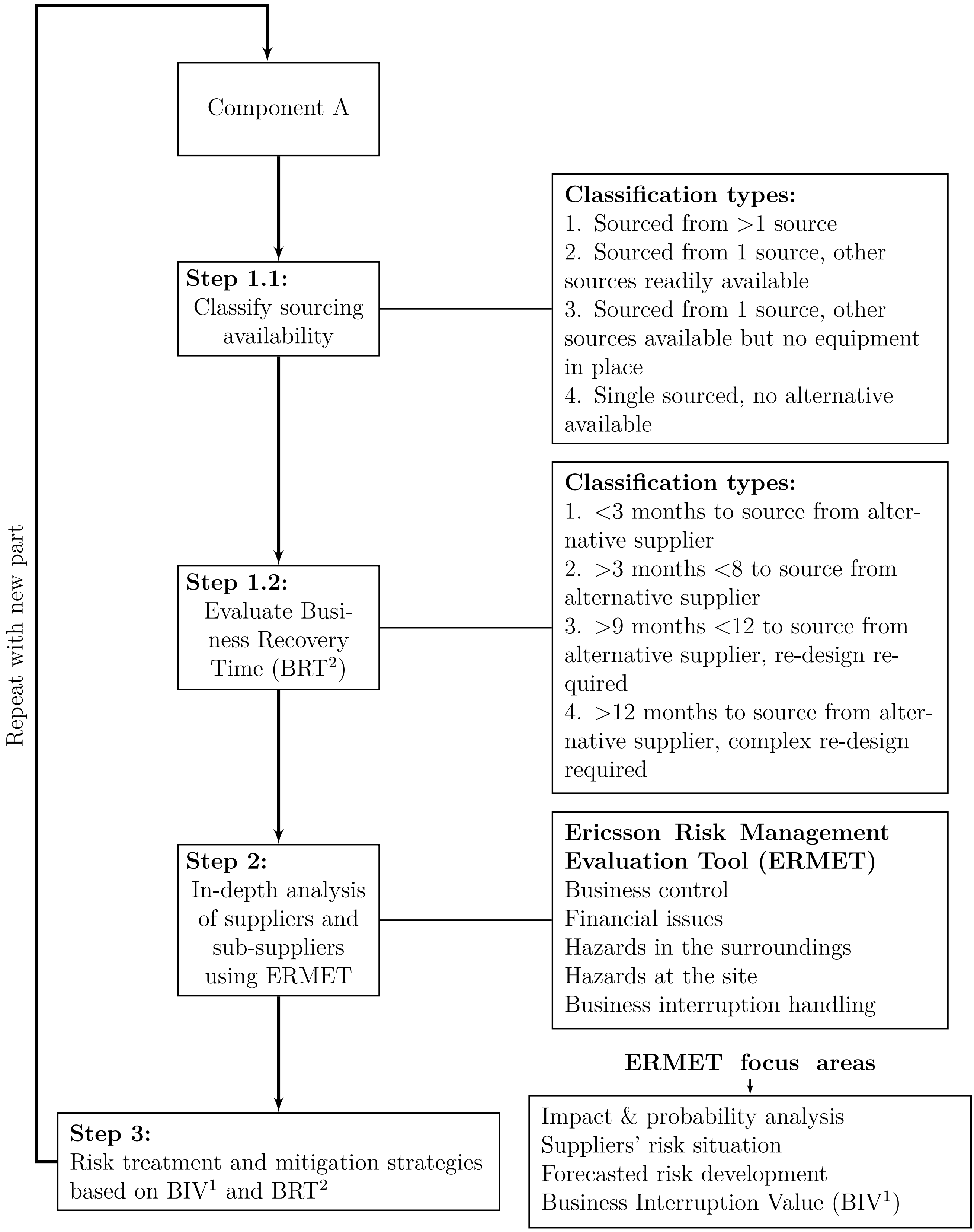


Figure 4.6: Ericsson's approach for component based risk management.

[1] **Business Interruption Value:** defined as the gross margin multiplied by the BRT plus extra costs such as idle capacity labor, equipment and carried inventory.

[2] **Business Recovery Time:** defined as the time required to find an alternative supply source.

4.2.4 Prioritized risk assessment tools for automotive supply chains

According to Zsidisin and Ritchie (2009), Dobrovnik, Kummer, and Huong Tran (2018) there has been a trend shift regarding proactive risk management in modern supply chains. The previous attitude towards proactive risk management has been skeptical and it was considered to cost more money than what it would save for the company. In the recent decade however, the attitude has changed and supply chain managers have gained an increased interest in proactive risk management with all that it entails (Zsidisin & Ritchie, 2009).

A crucial element of a successful proactive approach to risk management is to use appropriate tools for risk identification and risk analysis/evaluation (de Oliveira et al., 2017; Zsidisin & Ritchie, 2009). In a study by de Oliveira et al. (2017) the most important risk assessment tools throughout the phases of risk identification and risk analysis/evaluation were identified. The study was conducted using an Analytic Hierarchy Process based prioritization by interviewing five experts within automotive supply chains. The five most important risk assessment tools, as identified by de Oliveira et al. (2017), are presented below ordered by descending priority:

- Cost/benefit analysis
- Business impact analysis
- Scenario analysis
- Environmental risk assessment
- Failure Mode Effect Analysis

Each of these five risk assessment methods are described in more detail in the remainder of this section.

Cost/benefit analysis

The cost-benefit analysis evaluates whether or not a preventive investment is economically justifiable (Paltrinieri & Khan, 2016). In current supply chain risk management activities, preventive investments are often considered in order to mitigate risk areas (Zsidisin & Ritchie, 2009), and hence the cost-benefit analysis is gaining ground.

When evaluating if a risk mitigation investment is economically justifiable the costs of the investments and the expected benefits needs to be estimated. According to Paltrinieri and Khan (2016) the costs can be divided into initial cost, installation cost, operation-/maintenance cost, inspection cost, logistics/transport safety costs, contractor safety costs and other safety costs. Further Paltrinieri and Khan (2016) divides the benefits into supply chain, damage, legal, insurance, human, environmental, intervention, reputation and other benefits. When all of these costs and benefits are estimated and distributed over a suitable time period they need to be calculated in terms of net present value (Paltrinieri & Khan, 2016). After estimating the net present value the most beneficial decision can be made.

One of the major advantages with cost-benefit analysis is that it expresses the benefits in monetary terms, which makes it possible to take decisions based on quantitative data.

However, some challenges occur when trying to transform possible events into monetary terms (Rao, Sultana, & Kota, 2017; Paltrinieri & Khan, 2016). An example of such an event is if a company is to make a decision to either disregard or to take actions against some risks that could result in fatalities. In this case it is both challenging and controversial to value a human life (Rao et al., 2017; Paltrinieri & Khan, 2016)

Business impact analysis

A business impact analysis (BIA) is conducted to create an understanding of the potential effects of certain risks, should they occur within the company or its supply chain (Hiles & Brookfield, 2002; Torabi, Rezaei Soufi, & Sahebjamnia, 2014). Except from identifying the costs of a disruption, BIA can also be used for other objectives, such as establishing a maximum recovery time, described as time-to-survive by Simchi-Levi et al. (2015) and assess which resources are needed for a more efficient recovery (Hiles & Brookfield, 2002).

A BIA can be performed by identifying how the company creates value, either via manufacturing or service providing, and which processes that are needed for the company to maintain its daily operations. This can be done by sending out surveys to the managers concerned (Department of Homeland Security, n.d.) or by the four step approach: (1) Identifying key products, (2) Key products' breakdown structure, (3) Identifying of critical functions and (4) Estimating the continuity parameters, as presented by Torabi et al. (2014).

Scenario analysis

A scenario analysis is a risk assessment tool used to investigate possible future scenarios by using the uncertainties present in the company's supply chain (Dutta & Babbel, 2013; Hart & Doolan, 2017; Bachmann, 2006). By changing different parameters and uncertainties, different scenarios can be explored. This can assist management in developing suitable mitigation strategies for risk areas and to make the most beneficial decisions for the company (Dutta & Babbel, 2013; Hart & Doolan, 2017; Bachmann, 2006). It can also be seen as a simulation that is based on conditions that represents the company's current situation and/or the situation where the company has invested in risk mitigating actions (Gernaey & Sin, 2008). This however requires parameters and conditions that correspond to reality, which in turn will require inputs from multiple stakeholders from the company. Just as when conducting a Business Impact Analysis, the parameters used for a Scenario Analysis can incorporate both qualitative and quantitative data (Bachmann, 2006).

According to Hart and Doolan (2017) the developed scenarios can often help managers and other employees engage in proactive risk management by making the risks facing the company graspable. Due to this, scenario analyses is often suitable as a screening to identify the risks that should be analyzed further (Bachmann, 2006). For further analysis it is preferred to use either of the aforementioned tools described in this section (Bachmann, 2006).

Environmental risk assessment

The purpose of an environmental risk assessment (ERA) is to evaluate the likelihood that the company can cause environmental damage (Fairman, Mead, & Williams, 2008; EFSA, n.d.).

According to Gormley, Pollard, and Rocks (2011) ERA consists of four different steps, that should all be executed in order to provide valuable insights. These four steps are:

- **Hazard identification**: Identify potential hazards by investigating the company's waste disposal, emission volumes and particles, substance handling, usage of raw materials and packaging (Invest Northern Ireland, n.d.). Gormley et al. (2011) stresses the importance to also consider *'secondary hazards'* that may occur when preventing the primary hazard. An example could be the water damage that might occur while fighting a fire.

- **Assess the consequences**: In this stage the complete scope of consequences needs to be considered (Gormley et al., 2011). When estimating the impact of the consequences factors such as social and economical losses need to be assessed (Williams et al., 2008).

- **Probability assessment**: The probability of occurrence of a hazard needs to be estimated. This can be done by either directly approximating its probability or by using its historical frequency. However, many hazards can be difficult to assess using quantitative data, which may obstruct the results from being entirely reliable (Gormley et al., 2011).

- **Risk and uncertainty characterization** This stage is where you compile the insights from the other steps. By merging the insights regarding different risks likelihood of occurrence and their potential consequences, actions can be taken in order to mitigate the most significant environmental risks (Gormley et al., 2011).

Failure Mode and Effect Analysis

The failure mode and effect analysis (FMEA) is often used by producing companies to find the most vulnerable/critical components in their manufactured products (Kritzinger, 2016; Chandrasekaran, 2009; Kent, 2016). In the FMEA approach the significance an error would have, if it occurred within the lowest level of components, is evaluated. Using this method, risks mitigation actions can be prioritized based on how critical that specific component is for the system (Kritzinger, 2016; Chandrasekaran, 2009; Kent, 2016).

The FMEA is described by Kritzinger (2016) as a three step *'bottom-up'* approach consisting of: (1) finding in which ways components can fail and the probability of them doing so; (2) calculating effects these failures would have on the next hierarchy and on the system/product as a whole; (3) prioritizing the failure of components according to the size of their impact.

Kent (2016) states that the FMEA process will answer the three questions:

- *How can this product fail to perform as designed?*
- *What will happen if the product fails to perform as designed?*
- *How can we reduce the possibility of failure or the severity of the effect?*

The process for answering these questions is described in a similar way by the two authors, Kent (2016) and Kritzinger (2016), with only minor differences. Both processes include the steps of: defining the scope and the customer, defining potential failures, the effects of the failures and the causes of it, identify current controls for detecting causes, identify the risks and prioritize them, recommend actions and then re-assess and monitor the risks.

4.3 Disruptive events in the past

There is a lot to learn from history and the mistakes made by other companies. By studying previous disruptions at other companies operating in similar industries, measures can be taken in advance to anticipate and prevent similar disruptions by changing the current risk management processes (Manners-Bell, 2014). As described by Ferná Ndez, Toledo, Galli, Salomone, and Chiotti (2015), a disruptive event is a significant and unplanned change to the specification or the availability of an order.

Through academic research and case studies about previous disruptive events, this section aims to provide insights and answers to four key questions for each of the studied events:

- **Disruptions:**
  What type of disruption occurred?
- **Response strategy:**
  How did the affected companies respond to the crisis?
- **Implications:**
  What were the implications for the affected companies?
- **Managerial changes:**
  How did the risk management routines change after the disruptive event?

A selection of disruptive events, all of which heavily affected single or multiple companies and their supply chains, are presented in Table 4.1.

Table 4.1: Summary of selected disruptive events.

Industry	Disruption	Response Strategy	Implications	Managerial Changes
Mattel Inc., Toys (2007)	Supplier did not comply with regulatory requirements.	Recall of 21 million toys.	Fined $2.3M (C. Kerr, 2009). Estimated cost $30M (Story & Barboza, 2007).	Shifting toy production into factories Mattel own and operate (Story & Barboza, 2007).
Honda, Automotive (2002)	Introduction of U.S. steel import tariffs.	Airlift carbon sheet steel to the U.S.	Increased costs: $3000 per ton. Reduced material availability (Olson L., 2014).	Expanded supplier portfolio (Schwerin, 2005).
Continental Airlines, (2001)	September 11 terrorist attack.	Decision support system CrewSolver automatically reassigning flight crew.	$40M estimated savings over a 5 year period (Yu, Argüello, Song, McCowan, & White, 2003).	Increased managerial focus on recovery planning systems (Tang, 2006b).
Nokia & Ericsson, Telecom (2000)	Semiconductor plant fire in New Mexico.	(Nokia) Reconfigured phone design to accept other chips. (Ericsson) Undefined response strategy.	(Nokia) Maintained production, satisfied demand, increased market share (Tang, 2006b). (Ericsson) $400M estimated loss of revenue (Chopra, Reinhardt, & Mohan, 2007).	(Nokia) Modular product design. Dual sourcing. (Tang, 2006b) (Ericsson) New SCRM system, focused on minimizing risk exposure (Norrman & Jansson, 2004).
Toyota, Automotive (1997)	Fire at key supplier of critical component.	Initiated recovery effort involving 200 firms.	$195M estimated cost. Sales loss of 70000 vehicles (Norrman & Jansson, 2004).	Clustered firm networks. Partnered with new suppliers and set up alternative production sites (Nishiguchi & Beaudet, 1998).

The semiconductor plant fire accident in Albuquerque, New Mexico, (also know as the "Albuquerque accident"), and how it affected Ericsson in particular has been selected by the authors to be evaluated in more depth due to several reasons: Ericsson operates in a highly technical and volatile industry; The disruption received significant media coverage; The accident proved to be a major trigger for Ericsson to improve their supply chain risk management (Norrman & Jansson, 2004); Lastly, because Ericsson decided to openly share their new supply chain risk management approach, a lot of data were able to be retrieved and analyzed.

How Ericsson's supply chain risk management processes looked prior to the event, and a detailed description of how it changed after can be found in section 4.2.3.

4.3.1 High-impact, low-probability events

Most of the disruptive events exemplified in the previous section are what is called *'High-impact, low probability events'*, implying that the likelihood of occurrence is very small but the financial impact should the disruption occur is very large. For a supply chain manager to consider all the potential events that falls within this category is simply not feasible. Most researcher's agree on this part, reaching consensus that it's not doable as it would be too costly, too time consuming and provide too unreliable insights (Sigler, Shoemaker, Kohnke, Shoemaker, & Kohnke, 2017; Manners-Bell, 2014; Gurnani et al., 2012; Norrman & Jansson, 2004). What is suggested however, by different researchers, is what measures can be taken to make your supply chain more resilient to disruptions (Kalavar & Mysore, 2017; Manners-Bell, 2014; Tang, 2006b; Norrman & Jansson, 2004), described in detail in section 4.3.2.

A selection of additional high-impact, low-probability events are outlined in the remainder of this section to illustrate the concept further.

In 2010 the eruption of the Icelandic volcano Eyjafjallajökull shut down transportation across most of Europe, heavily impacting supply chains in the region (Olson L., 2014). According to Ohnsman, Einhorn, and Culpan (2011) the estimated economic impact of the event was in the billion dollar range, citing a the need for increased supply chain resilience.

In March 2011 a tsunami caused by an earthquake north of Tokyo destroyed a majority of the semiconductor manufacturing plants in the region. Japan's disrupted production, which at the time accounted for about 20% of the semiconductors used worldwide, forced organizations such as Samsung, Ford Motor Company and Boeing to halt their production as they lacked key components from their Japanese suppliers (Olson L., 2014).

Early 2011 in Germany, the automotive manufacturers Volkswagen, Porsche and BMW, all experienced a surge in demand that far exceeded their original forecasts. This was due to a booming demand in both the United States and China for German cars. As an effect, the lean production characterizing automotive manufacturing (Gurnani et al., 2012), resulted in several of the major auto manufacturers having to halt their production due to part shortages (Olson L., 2014).

4.3.2 Supply Chain Resilience

Instead of focusing on minimizing a selection of high-impact, low-probability events, many authors suggest focusing on maximizing supply chain resilience (Simba et al., 2017; Barroso, Machado, Carvalho, & Cruz Machado, 2015; Scholten et al., 2014; Waters, 2011). Christopher and Peck (2004, p.2) define supply chain resilience as *'the ability of a system to return to its original state or move to a new, more desirable state after being disturbed'*. This definition implies focusing attention on the internal organization instead of focusing on external parties (i.e. suppliers).

Ohnsman et al. (2011) propose strategies such as multiple sourcing, flexible manufacturing and logistics networks capable of alternative routing as means toward becoming more resilient. Sheffi (2005) suggest developing supply chain resilience by building in redundancy and flexibility by for example: keeping excess inventory, maintaining low capacity utilization, multi-sourcing, standardization, modular design and applying concurrent instead of sequential processes. Tang (2006b) propose nine different strategies for improved supply chain resilience, including: i) postponement, ii) strategic stock, iii) flexible supply base, iv) make-and-buy, v) economic supply incentives, vi) flexible transportation, vii) revenue management, viii) dynamic assortment planning and ix) silent product rollover.

One model for visualizing supply chain risk resilience is the *Resilience Triangle* (Sheffi, 2005). It illustrates how a disruption affects a company's supply chain performance and how it recovers over time. If specific recovery actions are mapped to their relative regained performance, conclusions regarding which recovery initiatives work well can be made.

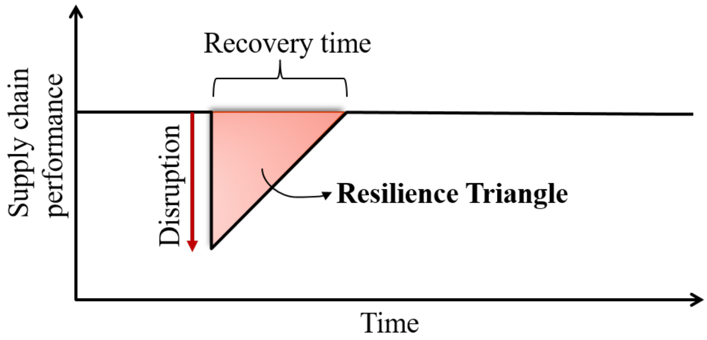


Figure 4.7: The Supply Chain Resilience Triangle.

Sheffi (2005) characterizes a company's response to risk in eight phases: i) eventual preparation to risk, ii) disruptive event occurrence, iii) first response, iv) initial impact, v) full impact, vi) recovery preparation, vii) recovery and viii) long term impact. By mapping each of these phases and their recovery impact using the resilience triangle, managers can make improved decisions regarding risk resource allocation in the future.

4.4 Risk categorization

In order to be able to improve internal supply chain risk management processes the risks need to be identified, mapped and categorized. There exist numerous different ways to categorize risks, such as internal and external as suggested by Kırılmaz and Erol (2017) as well as by Olson L. (2014); operational and disruptive (Yuan, 2010; Tang, 2006a); or economical, environmental, geopolitical, societal and technological (World Economic Forum, 2018). Which type of risk categorization a company utilizes is highly context dependent, and thus literature regarding risk categorization within the focus area of this study (electronics & automotive) is described in the following sections.

4.4.1 Risk categorization within the electronics industry

Two supply chain risk research papers within the electronics industry that emphasizes the need for risk categorization were identified through a literature review of 224 articles within the field of supply chain risk management made by Ho, Zheng, Yildiz, and Talluri (2015). A summary of the key risk categories brought up by the two articles is presented in Table 4.2.

Table 4.2: Supply chain risk categories in the electronics industry

Authors	Risk categories
Wagner and Bode (2008)	i) Demand side risks ii) Supply side risks iii) Regulatory, Legal and Bureaucratic risk iv) Infrastructure risks v) Catastrophic risks
Harland, Brenchley, and Walker (2003)	i) Strategic risk ii) Operations risk iii) Supply risk iv) Customer risk v) Asset impairment risk vi) Competitive risk vii) Reputation risk viii) Financial risk ix) Fiscal risk x) Regulatory risk xi) Legal risk

By comparing the risk categories in the research articles, differences regarding content can be identified. An overview of how the different categories correlate and overlap can be found in Table 4.3.

Demand side risk, as described by Wagner and Bode (2008), covers customer unforeseeable demand variations, relationship risks and bullwhip effects. To compare with **Customer risk** which takes a different perspective. Harland, Brenchley, and Walker (2003) defines customer risk as a vulnerability where customers can become less likely to place orders. Demand side risk and customer risk are partly covering the same risks, however, they are also failing to include some of the risks covered by each other. Demand side risks fails to include customer losses due to external events, however, Wagner and Bode (2008) are including these events in their 'catastrophic' risk category instead. Bullwhip effects is an example of a risk that is covered in Wagner and Bode's (2008) risk categorization, but is disregarded in Harland et al.'s (2003) categorization.

Supply side risks are defined as risks connected to suppliers which affect the efficiency of the company (Wagner & Bode, 2008). Examples of such risks are supplier capacity constraints, quality issues and financial instabilities of suppliers. This definition is similar to the definition of **Supply risk** as defined by Harland et al. (2003).

The **Regulatory, Legal and Bureaucratic risks** described by Wagner and Bode (2008) are similar to the **Regulatory** and **Legal risks** described by Harland et al. (2003). In short, these risk are linked to the potential occurrence of new/changed laws and regulations that could affect the performance of the supply chain. Furthermore it is dependent on the frequency of which they are changed. It also regards introduction of new barriers, such as trade and customs regulations (Wagner & Bode, 2008; Harland et al., 2003; Meulbroek, 2000).

Infrastructure risks are the disruptions in a firms infrastructure. These disruptions could, among other, occur due to machine breakdowns, IT-breakdowns, cyber attacks, hard- or software failures, vandalism, accidents and power failure (Wagner & Bode, 2008). These risks are similar to the risks described as **Asset impairment risks** which is the reduction of the utilization rate of firms infrastructure (Harland et al., 2003). In excess of asset impairment risks, infrastructure risk also covers the **Operational risks** described as events that impairs the company's capability to supply the demand (Harland et al., 2003).

The **Catastrophic risk** including e.g. force majeure, civil unrest and terror attacks (Wagner & Bode, 2008) has been included in Harland et al.'s (2003) **Supply**, **Customer risk** and **Operational risk**.

The four risk categories brought up by Harland et al. (2003) that is not included in Wagner and Bode's (2008) article are: **Strategic risk**, which is risks affecting the company's strategic implementations; **Reputation risk**, referring to the deprivation of goodwill; **Financial risk**, losses due to fluctuations/changes in the financial market; **Fiscal risk**, occurring because of taxational changes.

Table 4.3: Similarities in supply chain risk categories for the electronics industry

Wagner and Bode (2008)	Harland, Brenchley, and Walker (2003)
(Demand side risk)	(Customer risk)
Supply side risk	Supply risk, (Competitive risk)
Regulatory, Legal and Bureaucratic risk	Regulatory risk & Legal risk
Infrastructure risk	Asset impairment risk & Operational risk
Catastrophic risk	(Supply risk), (Customer risk) & (Operational risk)
	Strategic risk
	Reputation risk
	Financial risk
	Fiscal risk

Note: Parentheses implies that it is partly covered by the corresponding risk category.

4.4.2 Risk categorization within the automotive industry

The following section is based on three supply chain risk research papers about risk categorization within the automotive industry. Similar to the last section, these research articles were identified through the same literature review of 224 articles within the field of supply chain risk management made by Ho et al. (2015). Presented in Table 4.4 is a summary of the key risk categories brought up in the research articles.

Table 4.4: Supply chain risk categories in automotive industry

Authors	Risk categories
Blackhurst, Scheibe, and Johnson (2008)	i) Disruptions/disasters ii) Logistics iii) Supplier dependence iv) Quality v) Information systems vi) Forecast vii) Legal viii) Intellectual property ix) Procurement x) Receivables (accounting) xi) Capacity xii) Management xiii) Security
Wagner and Bode (2008)	i) Demand side risks ii) Supply side risks iii) Regulatory, Legal and Bureaucratic risk iv) Infrastructure risks v) Catastrophic risks
Trkman and McCormack (2009)	i) Endogenous risks [1] ii) Exogenous risks [2]

How the three risk categorization methods correlate is summarized in Table 4.5. The differences and similarities are described in the remainder of this section.

Disruptions/Disasters, defined by Blackhurst et al. (2008), includes both internal and external risks, man-made and force majeure. Potential internal risks include: labor disputes, plant disasters and labor availability. External risks as described by Blackhurst et al. (2008) are: force majeure, supplier bankruptcy, war, terrorism and political issues. The internal and external disruption/disaster risks cover the same risk areas as **Catastrophic risks** and parts of **Supply side risks** and **Infrastructural risks**, as described by Wagner and Bode (2008). Catastrophic risks includes e.g. force majeure, civil unrest and terror attacks, and the remaining areas, such as supplier bankruptcy and labor disputes are covered by Supply side risks and Infrastructural risks (Wagner & Bode, 2008). According to Trkman and McCormack's (2009) these areas are covered by the discrete events category within the **Exogenous risks**.

Supply side risks, as described by Wagner and Bode (2008), is a collective category for the **Supplier dependency, Quality, Procurement, Intellectual property, Logistic, Information systems** and **Forecast** risks defined by Blackhurst et al. (2008). However, considering Information systems and Forecast, only one part of each is covered

[1]**Endogenous risks** is defined by Trkman and McCormack (2009) as a source of uncertainty from inside the SC and can lead to changing relationships between focal firm and suppliers where the most notable kinds are market and technology turbulence.

[2]**Exogenous risks** is defined by Trkman and McCormack (2009) as a source of uncertainty from outside the SC that can be divided into discrete events (e.g. terrorist attacks, contagious diseases) and continuous risks (e.g. inflation rate, changes in consumer price index)

by Supply side risks, namely level of system integration and lead time variance (Blackhurst et al., 2008; Wagner & Bode, 2008). All of these risks can be considered being uncertainties inside the focal company's supply chain, and is therefore classified as **Endogenous risks**. The procurement risk category includes risks regarding exchange rates (Blackhurst et al., 2008) which is continuous and hence, classified as **Exogenous** according to Trkman and McCormack (2009).

Demand side risks are the risks that may occur downstream in the supply chain (Wagner & Bode, 2008). Demand side risks consists of risks related to the following of Blackhurst et al.'s (2008) risk categories:

- **Logistics**, such as timely deliveries, delivery responsiveness, customs, number of transfers, overload in the channel, infrastructure limitations or problems and port issues.
- **Forecasts**, such as forecast accuracy and variations in product demand.
- **Receivables (accounting)**, dependant on number of customers and customer's financial strength .
- **Inventory**, such as holding cost, product value, storage requirements and rate of product obsolescence .
- **Capacity**, such as capacity cost and flexibility.

These risks are covered by Trkman and McCormack's (2009) risk categorization using the endogenous and exogenous risk categories, that is, uncertainties from outside and inside the supply chain.

The **Regulatory, Legal and Bureaucratic risks** defined by Wagner and Bode (2008) is a more thorough description of the risk area than the **Legal** risk category, as defined by Blackhurst et al. (2008). As described in chapter 4.4.1 the Regulatory, Legal and Bureaucratic risks includes potential occurrence of new/changed laws and regulations and new barriers, such as trade and customs regulations that may affect the performance of the supply chain. It also considers the frequency of which they are changed (Wagner & Bode, 2008). On the other hand, Blackhurst et al.'s (2008) definition of Legal risks only includes legislation regarding import regulations and regulations for global sourcing. However, the risks mentioned by Wagner and Bode (2008) concerning political issues, that is missing in Blackhurst et al.'s (2008) Legal category, is covered in the **Disruption/Disaster** category. These risks are covered by the **Exogenous risks**, as described by Trkman and McCormack (2009).

Infrastructure risks is the disruptions that can occur in the firms infrastructure. As mentioned in chapter 4.4.1 this includes machine breakdowns, IT-issues, power failure etc. (Wagner & Bode, 2008). This is covered by Blackhurst et al.'s (2008) **Security** and **Disruption/Disaster** risk categories. The security category includes system security, IT attacks, theft and vandalism (Blackhurst et al., 2008). Events such as major machine breakdowns and plant fires are included in Disruptions/Disasters (Blackhurst et al., 2008).

The **Management** risk category including lack of visibility within the organization and risk of lacking communications (Blackhurst et al., 2008) is not covered by either of the other authors.

Table 4.5: Similarities in supply chain risk categories for the automotive industry

Blackhurst, Scheibe, and Johnson (2008)[3]	Wagner and Bode (2008)	Trkman and McCormack (2009)
Disruptions/Disasters	Catastrophic risks, (Supply side risks), (Infrastructural risks)	(Exogenous risks)
Supplier dependencies, Quality, Procurement, Intellectual property, (Logistics), (Information systems), (Forecast)	Supply side risks	Endogenous risks, (Exogenous risks)
Forecast, Receivables, Inventory, Capacity, (Logistics)	Demand side risks	(Endogenous risks), (Exogenous risks)
Legal, (Disruptions/Disasters)	Regulatory, Legal and Bureaucratic risk	(Exogenous risks)
Security, Information systems, (Disruptions/Disasters)	Infrastructure risks	(Endogenous risks), (Exogenous risks)
Management		

Note: Parentheses implies that it is partly covered by the corresponding risk category.

4.5 Supplier risk and performance indicators

Key risk indicators (KRIs) and key performance indicators (KPIs) within risk management are important as they allow risks to be aggregated and quantified (Leończuk, 2016; Baker, 2016). KRIs are defined by ISACA industry association as:

> *"Metrics capable of showing that the enterprise is subject to, or has a high probability of being subject to, a risk that exceeds the defined risk appetite."* (Information Systems Audit and Control Association., 2009, p.27)

Whereas the more commonly used concept of KPIs has multiple definitions, used interchangeably in literature, such as:

> *"A performance measure can be defined as a metric used to quantify the efficiency and/or effectiveness of an action."* (Neely, Gregory, & Platts, 1995, p.80)

> *"A performance indicator is a variable which indicates the effectiveness and/or efficiency of a process, system or part of a system when compared with a reference value."* (Drongelen, 1999, p.81)

[3] All of Blackhurst et al.'s (2008) primary categories are further divided into the subcategories *internal* and *external* risks

This section aims to highlight the most commonly used supplier risk and performance indicators found throughout the literature review and provides the reader with an understanding of what they are are and how they can be measured. Primarily indicators used within the electronics and automotive industry, retrieved by studying business cases, are presented.

According to Leończuk (2016), there are hundreds of different indicators for measuring supplier performance. What falls under the category of being a risk versus performance indicator varies in literature. For example, Blackhurst et al. (2008) propose risk indicators such as: rate of on-time deliveries, defects per million, lead time variance, dependence on single source of supply and ease of problem resolution. Shin, Collier, and Wilson (2000) on the other hand, propose similar metrics but refer to them as performance indicators instead.

Other authors perceive risk indicators and performance indicators as being contradictory to each other, and hence suggests to keep them separate. Thekdi and Aven (2016) argue that one of the key principles within risk management, namely to reduce risk exposure, is directly in conflict with increasing operational performance. This concept is usually referred to as risk appetite (Khojasteh, 2018), defined by ISO Risk Vocabulary (2009, Ch. 3.7 - Terms relating to risk evaluation) as the *'Amount and type of risk that an organization is willing to pursue or retain'*. Implying that, the larger the risk appetite a company has, the better operational performance they will have. Consider the case of using a single source of supply, it allows for increased economies of scale and bargaining power toward the supplier - which reduces costs - but if a disruption occurs the consequences will be more severe than if multiple supply sources had been used.

Thekdi and Aven (2016) further illustrates the differences between performance management and risk management by comparing their respective benefits, as outlined in Table 4.6.

Table 4.6: Performance management benefits versus risk management benefits.

Performance Management Benefits	**Risk Management Benefits**
Management to achieve high-level performance, with focus on opportunity – maximize positive consequence.	Management to maintain high-level performance, with focus on loss – minimize negative consequences.
Driven to meet high level goals	Driven to meet high level goals, with focus on uncertainty in goal attainment.
Reliance on data-based metrics.	Use of data-based metrics with also inclusion of societal context.
Setting performance goals to meet shareholder or other direct stakeholder values.	Setting performance goals to meet a direct and indirect stakeholder values.
Formulation of well-defined quantitative objectives.	Formulation of well-defined quantitative objectives.
Alignment of processes to meet well-defined quantitative objectives for achieving high-level performance.	Alignment of processes to meet well-defined quantitative objectives for avoiding or recovering from negative consequences.

Note. Reprinted from: *'An enhanced data-analytic framework for integrating risk management and performance management'*, by Thekdi, S., Aven, T., 2016, Reliability Engineering & System Safety, 283, Copyright 2016 by Elsevier Inc.

Due to the varying definitions found in literature, the indicators presented in the remainder of this section can be classified as either KPIs and/or KRIs. What this section aims to highlight is commonly used indicators for measuring risk and performance levels within the supplier base, both short-term and long-term, and as such it does not focus on *Performance* or *Risk* indicators in isolation.

As described in Section 4.4.2, the categories in which specific KPIs/KRIs are grouped varies between companies and industries. This section presents risk and performance indicators sorted under four categories, selected by the authors, including: (1) *Operational performance indicators*, (2) *Financial performance indicators*, (3) *External risk indicators* and (4) *Sustainability performance indicators*. These categories were selected by the authors after having conducted an extensive literature review of various risk categorization frameworks (see section 4.4). Furthermore, argued by the authors, these categories provide a clear distinction as to under which category a specific indicator belongs while also managing to encapsulate all the indicators found throughout the study.

It's important to keep in mind that any KPI measurement depends on two factors: (1) trend over time; and (2) relationship to industry averages (Ostring, 2004), implying that a *'low'* KPI is not necessarily a bad thing as it may still be higher than industry average.

Operational performance indicators

The indicators presented in Table 4.7 are examples of metrics that measure the operational performance of a supplier. A strong value corresponds to a supplier performing at a high operational level, which also corresponds to low-risk. Whereas a weak value indicates low supplier operational performance, corresponding to a high level of risk.

Table 4.7: Supplier operational performance indicators.

KPI	Description	Source
On-time delivery rate	Percentage of shipments received on-time	(Blackhurst et al., 2008)
Order fulfillment rate	Percentage of shipments with 100% order fulfillment	(Ravindran, Ufuk Bilsel, Wadhwa, & Yang, 2010; Blackhurst et al., 2008)
Order backlog	Average order backlog	(Blackhurst et al., 2008)
Delivery responsiveness	Days required for express deliveries, capability to change order sizes	(Ravindran et al., 2010; Blackhurst et al., 2008)
Lead time variance	Fluctuating lead time, min and max lead time	(Ravindran et al., 2010; Blackhurst et al., 2008)
Lead time	Time between order placed and order received	(Jung, Lim, & Oh, 2011; Blackhurst et al., 2008)
Defects / million	Defect units received as a percentage of shipment volume	(Ravindran et al., 2010; Blackhurst et al., 2008)
Contractual length	Negotiated length of contract	(Blackhurst et al., 2008)
Back-up inventory	Supplier's level of back-up inventory	(Blackhurst et al., 2008)
Supplier capacity utilization	Percentage of manufacturing capacity used by supplier	(Blackhurst et al., 2008)
Supplier capacity flexibility	Ability to increase/decrease output	(Blackhurst et al., 2008)
Ease of problem resolution	Time and effort required to solve quality problems	(Blackhurst et al., 2008)
Contractual length	Negotiated length of contract	(Blackhurst et al., 2008)
Technology	The level of technological capabilities of suppliers	(Jung et al., 2011)
No. of customers	Number of customers served by the supplier and their respective capacity allocation	(Blackhurst et al., 2008)
IT System security	Measures taken to safeguard IP & software	(Wagner & Bode, 2008; Blackhurst et al., 2008)

Financial performance indicators

Table 4.8 presents a selection of indicators for measuring a supplier's financial performance. These indicators can be used to assess the financial health of a supplier and to develop a financial risk profile. The required financial data can be obtained via financial statements, credit reports, banks, trade references or explicitly be specified in the contract to be shared directly by the supplier (Gordon, 2005).

Table 4.8: Supplier financial performance indicators.

KPI	Description	Source
Operating cash flow	Indicates ability to generate sufficient positive cash flow to grow operations	(Hornungová & Milichovský, 2019; Gerber, 2018)
Operating income margin	Operating income divided by net sales	(Hornungová & Milichovský, 2019; Ostring, 2004)
Working capital	Difference between current assets and current liabilities	(Ostring, 2004; Gerber, 2018)
Net sales change	Rate at which sales are increasing/decreasing compared to previous period	(Ostring, 2004)
Debt to equity ratio	Total liabilities divided by shareholder's total equity	(Gerber, 2018)
Profitability	How efficiently the company is using its assets	(Hornungová & Milichovský, 2019; Ostring, 2004)
Return on equity	Net income divided by average shareholder's equity	(Hornungová & Milichovský, 2019; Ostring, 2004; Gerber, 2018)
Return on assets	Net income divided by average total assets	(Hornungová & Milichovský, 2019; Ostring, 2004)
Net asset turnover	Net sales divided by average net assets	(Ostring, 2004)
LOB revenue vs target	Line-of-business revenue compared to target revenue	(Gerber, 2018)
LOB expenses vs budget	Line-of-business expenses compared to budgeted expenses	(Gerber, 2018)
Accounts payable turnover	Rate at which suppliers are paid off: Total cost of sales over a period T divided by average accounts payable	(Ostring, 2004; Gerber, 2018)
Accounts receivable turnover	Ability to collect due payments: Total sales over a period T divided by average accounts payable	(Ostring, 2004; Gerber, 2018)
Inventory turnover rate	Sales over a period divided by average inventory	(Ostring, 2004; Gerber, 2018)
Liquidity	Current assets divided by current liabilities	(Hornungová & Milichovský, 2019; Ostring, 2004)

Quick ratio	Current assets exclusive inventory, divided by current liabilities	(Ostring, 2004)
Interest coverage	Operating income divided by annual interest expenses	(Ostring, 2004)

Ostring (2004) suggests a process consisting of three stages when assessing financial risk/performance of suppliers, and suggests specific KPIs to evaluate in each stage, as is summarized in Table 4.9. The generic process for how poor supplier financial performance can be identified, as proposed by Ostring (2004), consists of first identifying indicators for low profitability, secondly identifying signs of weak efficiency and solvency, thirdly by identifying direct signs of financial difficulties (such as selling of company assets).

Table 4.9: Risk indicators for assessing financial risk in three stages.

Stage	**Description**	**KPIs to monitor**
Stage 1: Low profitability Risks are rising as cash flow from operations is decreasing.	1. Decreasing sales and profit margin 2. Increasing administrative and R&D costs relative to sales 3. Growing inventories compared to total assets	1. Gross profit margin 2. Operating profit margin 3. Return on assets 4. Return on equity 5. Net sales turnover
Stage 2: Weak efficiency and solvency Risks are rising when signs of insufficient funding appear.	1. Payments to suppliers become slower 2. Raw material shortages appear 3. Credit risk increases	1. Liquidity 2. Quick ratio 3. Working capital 4. Debt ratio 5. Equity ratio 6. Interest coverage
Stage 3: Weak solvency and profitability Risks are high when serious signs of financial difficulties appear.	1. Selling of assets 2. High level of debt 3. Fall in credit rating	(Same as stage 2)

External risk indicators

Table 4.10 presents indicators for assessing external risks related to selecting a specific supplier. These are risks related to the geographic position of the supplier, the legislative environment in which the supplier operates and risks which neither the supplier nor the buyer have any control over (such as force majeure).

Table 4.10: External risk indicators

KPI	**Description**	**Source**
Labor disputes	Commonality of disputes and union conflicts	(Trkman & McCormack, 2009; Blackhurst et al., 2008)

Labor availability	Access to required competencies, unemployment rate	(Blackhurst et al., 2008)
Disastrous events	Frequency and magnitude of disruptive events (fires, force majeure, etc.)	(Wagner & Bode, 2008; Trkman & McCormack, 2009; Blackhurst et al., 2008)
Exchange rate risk	Volatility of exchange rate, inflation trend	(Blackhurst et al., 2008)
Customs regulations	Likelihood of increased regulations and legislative actions such as tariffs	(Wagner & Bode, 2008; Trkman & McCormack, 2009; Blackhurst et al., 2008)
Environmental legislation	Likelihood of increased environmental legislation	(Wagner & Bode, 2008)
Transfer points	Number of transfer points from point of origin to destination	(Blackhurst et al., 2008)
Transportation alternatives	Number of alternative modes of transport & 3PL providers available	(Blackhurst et al., 2008)

Sustainability performance indicators

The first research that incorporated environmental sustainability in the design of a supplier rating system was performed by Noci (1997). After which multiple researchers developed additional criteria, categories and subcategories for sustainable/green supplier selection (Bai & Sarkis, 2010; Dai & Blackhurst, 2012; Neumüller, Lasch, & Kellner, 2016). Based on a study by Ghadimi, Dargi, and Heavey (2017), performed on an automotive spare parts manufacturer, the following supplier sustainability performance indicators were suggested (see Table 4.11).

Table 4.11: Supplier sustainability performance indicators.

Indicator/criterion	**Description**
Environmental performance	Indicates how well a supplier is driving internal environmental audits and aligning with external environmental policies.
Green image	Supplier's green image on the market with capabilities of manufacturing green products.
Pollution control	Suppliers capability to control and align emission levels with external environmental policies.
Green competencies	Supplier's ability to reduce the ecological impact of their operations using various green technologies.
Green design	Supplier's capability to design environmental friendly products.
Health and safety	Supplier's ability to provide effective systems for protecting their employees.
Employment practices	Supplier's usage of socially responsible employment practices (child labour, discrimination, flexible hours).
Local communities influence	Supplier's contribution to its local communities, such as supporting community projects, social cohesion, economic welfare and education.
Contractual stakeholder influence	Supplier's interest in establishing a long-term relationship and commitment to social development strategies over time.

Ghadimi et al. (2017) further groups the supplier sustainability indicators into two categories: (1) *environmental* and (2) *social*. Where the *environmental* category includes environmental performance, green image, pollution control, green competencies, green design and the *social* category includes health and safety, employment practices, local communities influence and contractual stakeholder influence. Zimmer, Fröhling, and Schultmann (2016) emphasizes the difficulties related to quantifying the social sustainability criterion as one of the main obstacles for companies when attempting to take social sustainability into account when evaluating suppliers.

4.6 Future of the automotive industry

This section outlines the primary trends within the automotive environment. Because the case company Aptiv is primarily operating within the automotive industry and due to the rapid introduction of vast amounts of new technologies in vehicles in recent years, this section aims to highlight what challenges the automotive industry is expected to face in the coming years.

The automotive industry is currently under a rapid development phase. New technologies are not only challenging the current cost structures of a vehicle, but its entire value proposition (Winkelhake, 2018; Ferràs-Hernández, Tarrats-Pons, & Arimany-Serrat, 2017; Kuhnert, Stürmer, & Koster, 2018; Gao, Kaas, Mohr, & Wee, 2016; Miller, 2017). Investments in automotive technology start-ups have been increasing significantly in recent years due to several emerging trends, including: (1) Shared mobility, (2) Autonomous vehicles, (3) Electrification and (4) Connectivity.

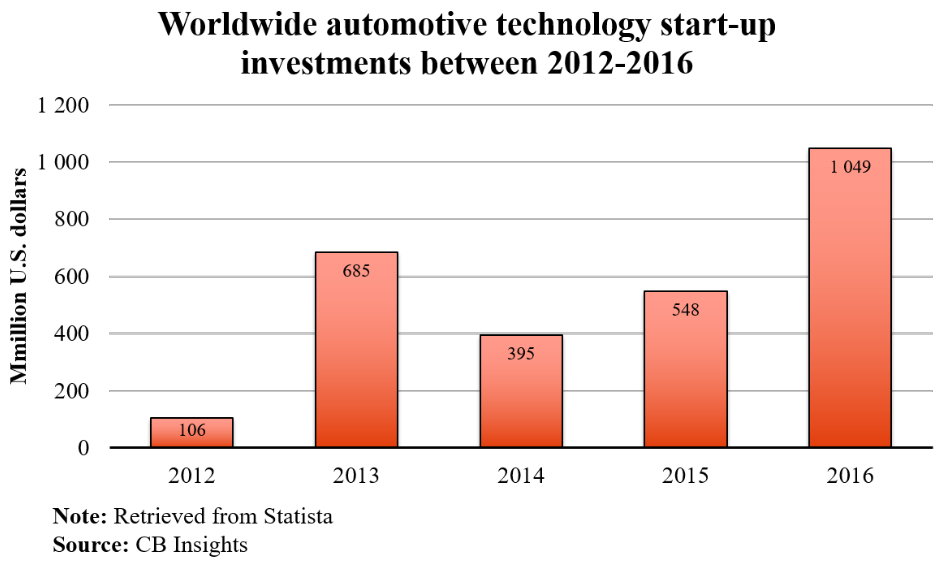


Figure 4.8: Worldwide automotive technology start-up investments between 2012-2016. Data retrieved from Statista (2019).

Even if consensus is that the automotive industry is changing, different authors and institutions are highlighting different aspects of it. The remainder of this section presents a summary of the most significant trends in the automotive industry according to the studied literature.

4.6.1 Transition towards more technically advanced vehicles

Many authors describe the upcoming vehicle sharing platforms in combination with electrified and autonomous vehicles as the most crucial drivers for change in the automotive industry (Ferràs-Hernández et al., 2017; Winkelhake, 2018; Kuhnert et al., 2018; Gao et al., 2016).

Shared mobility

The transition towards shared and on-demand mobility has started and will continue to grow. Gao et al. (2016) states that by 2030, 10 percent of all vehicles sold will be shared vehicles and that they will represent 30 percent of the covered miles. This implicates that the usage and the ownership of vehicles will change from every person/family owning one vehicle for all purposes to a system where a more tailored choice of vehicle can be made depending on the situation (Gao et al., 2016; Ferràs-Hernández et al., 2017).

In the long run, shared mobility is expected to transform the business model of automotive manufacturers from selling vehicles to end consumers for a one-time cost to a more continuous revenue stream through an on-demand structure (Winkelhake, 2018).

Kuhnert et al. (2018) describes that even though sharing arrangements have been tried out in denser populated areas previously, it is mostly in terms of pilot projects. These arrangements however, will become more profitable with the launch of autonomous vehicles.

Autonomous vehicles

The adoption rate of autonomous vehicles will differ depending on the technical and regulatory barriers that are put in place (Gao et al., 2016; Martínez-Díaz & Soriguera, 2018; Winkelhake, 2018). Nevertheless, forecasts have been made stating that by 2030 more than 30 percent of vehicles in larger cities will be autonomous (Winkelhake, 2018) and that 40 percent of the mileage covered in Europe is expected to be covered by autonomous vehicles (Kuhnert et al., 2018). The introduction of these vehicles will serve multiple purposes, ranging from safer rides, greater comfort and reduced environmental impact (Gerla, Lee, Pau, & Lee, 2014).

Autonomous and more technically advanced vehicles open up the automotive industry for new suppliers currently in the IT and high-tech industry (Miller, 2017). According to Cornet et al. (2019) vehicle software has an annual growth rate of 11 percent and that it by 2030 will hold 30 percent of the vehicle value. Further stating that car electronics will comprise an additional 25 percent of the value, implying that by 2030, 55 percent of total vehicle value will be generated by electronics and software.

Electrification

According to (Kuhnert et al., 2018) 55 percent of new cars sold is expected to be electrified by 2030. The electrification of vehicles will contribute to reducing green house gas emissions and noise levels (Kuhnert et al., 2018). Multiple automotive manufacturers such as General Motors, Volvo, Mercedes-Benz and Jaguar Land Rover have already announced plans to electrify their portfolio in the coming years. Moreover, China - where more than 40% of electric vehicles today are manufactured - is estimating annual sales of pure electric and hybrid vehicles to reach two million by 2020 (PwC Canada, 2018).

Just like with autonomous vehicles, electrification brings with it many challenges. Such challenges include setting up charging infrastructure, new technologies entering the vehicles, battery capacity limitations and battery deterioration over time. Moreover, unfavorable battery economics is expected to remain a profitability barrier for the next two or three product life cycles despite battery prices having declined by ~80% since 2010 (McKinsey, 2017).

Connectivity

In addition to these three drivers for change Kuhnert et al. (2018), Gao et al. (2016) and Roland Berger (n.d.) stresses the importance of connectivity. Connectivity is the ability to connect to other computers (Winkelhake, 2018), which for a vehicle primarily consist of *'car-to-car'* or *'car-to-infrastructure'* connectivity (Kuhnert et al., 2018). Apart from further increasing the share of software within the vehicle this also opens up for new revenue streams for the automotive supply chain (Gao et al., 2016). According to Berger-De Leon, Reinbacher, and Wee (2018) smart products, of which vehicles are becoming a natural part, can generate value for the company in three ways. Firstly, it can generate insights about its customers in order to optimize user interfaces, functionality and marketing. Secondly, it can generate additional sales by introducing new features and subscription models. Finally, it can also help build customer loyalty. Until the year of 2030, these recurrent revenues is expected to grow from 30 billion dollars a year to 1.5 trillion dollars within the automotive industry. In addition to this, new car sales is expected to grow in revenue with approximately 2 percent each year and the aftermarket revenues is expected to grow slightly more than the vehicle sales due to larger needs for maintenance on shared vehicles. Accumulated the per year growth of the automotive market is expected to be close to 4.4 percent. How these revenue streams are expected to change is depicted in Figure 4.9.

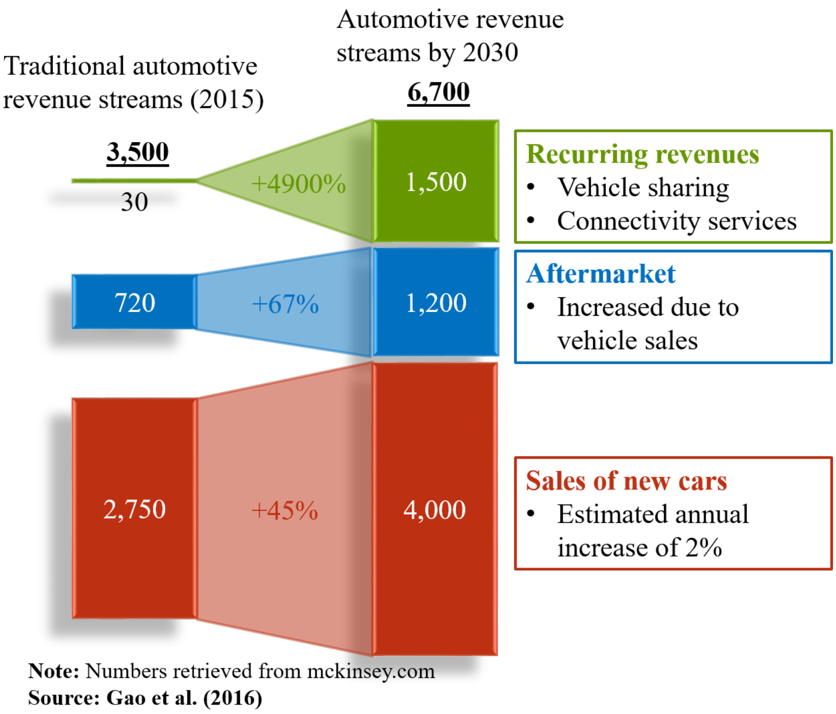


Figure 4.9: Expected revenue growth for the automotive industry, 2015 to 2030, separated into three streams of revenue. Data retrieved from Gao, Kaas, Mohr, and Wee (2016).

The effects on vehicle sales and usage

When the shared, electrified and autonomous vehicles become more common, the total car inventory is expected to decrease (Martínez-Díaz & Soriguera, 2018; Kuhnert et al., 2018). In Europe it is expected to decrease from 280 million cars in 2017 to 200 million in 2030 (Kuhnert et al., 2018). Despite the decreasing car inventory, car sales is still expected to grow (Gao et al., 2016). Kuhnert et al. (2018) also describes that the traveled passenger kilometers in Europe is expected to increase from 3.7 trillion to 4.2 trillion in 2030. The same trends can be seen in other parts of the world (Hasenberg, Bernhart, Schlick, & Winterhoff, 2015; Kuhnert et al., 2018). This implies that each car will be travelling more kilometers per day and per lifetime than before.

Other implications

The fast paced development towards increased spending on vehicle software within the automotive industry is forcing OEMs to collaborate with new, untested suppliers in order to stay competitive (Winkelhake, 2018). The increased importance of software and big data could even change the current power balance between the OEMs and the suppliers (Cornet et al., 2019).

Cornet et al. (2019) state that European OEMs have to change their core competencies to stay competitive and that non-automotive IT and high-tech actors are gaining market shares by the minute. The fast paced development and the fierce competition from Asian manufacturers are forcing European manufacturers to enter new collaborations with previously unknown suppliers. The technology rush within automotive supply chains and the lack of experience in handling software development is making the software development difficult to control. Nowadays, a car software suite consists of approximately 100 million lines of code, four times more than that of a fighter jet (Visual Capitalist, 2015).

In summary, software is gaining larger share of total spending in vehicle production. This brings with it four challenges: 1) Change of core competencies and transforming business models 2) Shifting power from OEMs to suppliers 3) Collaboration with new suppliers 4) Increasing software complexity.

4.6.2 Other trends

In recent years automotive manufacturers have had to decrease the vehicle's emission levels in order to cope with environmental regulations. If automotive manufacturers fail to comply with these added regulations penalty fees have to be payed which could deflate the already strained margins (Ferraris, Madlani, & Nakal, 2018; European Commission, n.d.).

The requirement for reduced time-to-market for new development projects within the automotive industry is also increasing (Katzenbach, 2015; Gottschalk & Kalmbach, 2007). The OEMs are trying to reduce the development times in order to increase the vehicle's life cycle (Katzenbach, 2015). In addition to this, the number of product variations have rapidly increased during the 21st century which has led to increased usage of modular vehicle designs (Katzenbach, 2015).

The automotive industry is also challenged from a cost perspective. Costs for components and services are increasing and cannot be pushed downstream to the end consumer because of a high price elasticity (Qin, 2014; Power, 2002). This is forcing both suppliers and OEMs to improve their supply chains by cutting costs.

Strategic partnerships between key automotive players is also on the rise due to the increasingly massive investments needed to develop new technologies. Late 2018 Honda partnered with General Motors' in developing self-driving cars (GM Media, 2018); BMW is collaborating with Intel and Fiat since the early 2000s (Camuffoo & Volpato, 2002); and Daimler is partnering with Bosch (Bomey, 2018).

4.7 Risk management trends

Supply chains are growing more vulnerable to disruptions and the need for efficient and reliable risk management processes is increasing (Geraint, 2015; Pearson, Crosnier, Kaltenbach, Schatteman, & Hanifan, 2014; van Kessel, 2014; Marchese & Paramasivam, 2013; Butner, 2010). The scale and complexity of risks that companies supply chains are facing have changed in recent years, especially for automotive manufacturers (Stolz, Lierow, & Vedder, 2018).

These changes are forcing companies with immature risk management procedures to rethink their way of working (Pearson et al., 2014; van Kessel, 2014; Butner, 2010). Different authors and institutions are recommending different approaches for how to cope with the new risk management landscape, however many approaches provide solutions similar to the ones provided by Geraint (2014). Geraint (2014) is dividing the new approaches into four main areas: *'Identifying and assessing risk'*, *'Quantifying and prioritizing risk'* and *'Mitigating risk and speeding recovery'*.

Identifying and assessing risk

Identifying and assessing risk in the supply chain has traditionally been performed by asking tier-1 suppliers for information about the sub-tier suppliers, however, they are often reluctant to do so. This is resulting in only 79 percent risk visibility into first-tier suppliers, 36 percent into second-tier and 17 percent and less into third and above tier suppliers (Geraint, 2014). The second most common approach, according to a CSCO survey from 2014 where 942 companies were interviewed, is to identify risk exposure by analyzing historical data. Additional methods and their frequency of usage are illustrated in Figure 4.10.

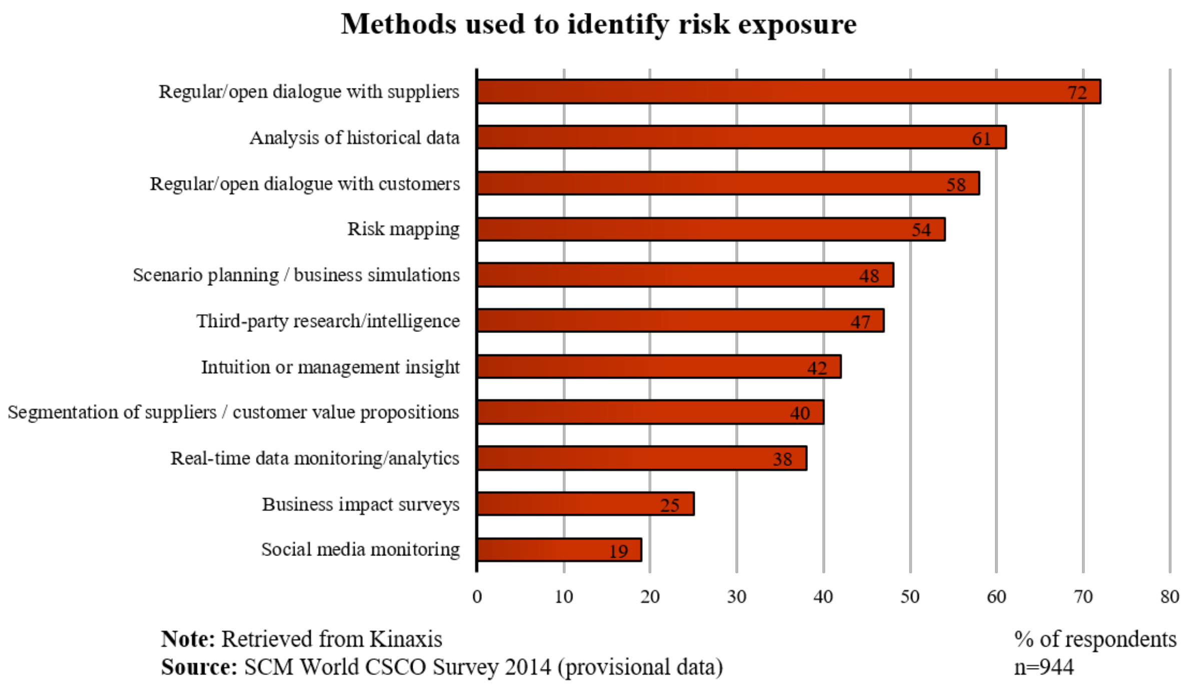


Figure 4.10: Common methods used to identify risk exposure. Data retrieved from Geraint (2014).

Predictive analytics has been a hot topic on the demand side for many years, with advanced forecasting models that consider a vast amount of input data in order to make more well-informed demand forecasts. On the supply side however it is less established, but multiple new approaches for how to detect early supply side risk indicators are starting to emerge in industry.

Automotive supplier BorgWarner found that traditional methods for assessing supplier risk failed to anticipate emerging risks quickly enough. To tackle this, they designed an early warning system that utilizes supplier performance data directly from their SAP system using a mathematical model known as *Hidden Markov*. The system identifies patterns in the data, such as planned versus actual deliveries, and uses them to predict the likelihood of sub-par performance in the coming weeks (Geraint, 2014).

Another tool for early risk identification is using geographic analytics. This is used today by companies such as HP, Cisco and IBM to assess risk within their supply chains. Cisco is utilizing *heat maps* for visualizing the impact of disastrous events on specific supplier locations. IBM uses a geospatial map to track potentially disruptive events, such as regional hostilities and global floods (Geraint, 2014).

Moreover, IBM utilizes a software suite for scanning social media by detecting certain keywords and phrases which is then analyzed before being forwarded directly to managers on site at potentially affected locations. BMW is another example of a company that has started to make use of social media to anticipate supply risk. They use a system called Enterprise 2.0 that takes unstructured data from multiple social media platforms, blogs, wikis and chatrooms, analyses and aggregates it before forwarding the data to an iPad app directly accessible by supply chain managers (Geraint, 2014). Additional predictive risk identification tools are starting to emerge using emerging technologies such as artificial intelligence and big data analytics (Lin & Hsu, 2017; Capgemini Consulting, 2017; Geraint, 2014), with practical systems offered by companies such as Resilinc and Achilles.

The two primary emerging areas for predictive risk analysis, most commonly referenced in literature are:

- **Geographic analytics.** Using real-time data concerning global incidents (extreme weather, earthquakes, tsunamis, etc.) to assess if their impact in any way can affect the company's supply chain in terms of infrastructure, production facilities or warehouses. An example map is illustrated in Figure 4.11.
- **Social media analytics.** Gathering data from social media in order to predict events that potentially can affect the supply chain. This can be done by searching and tracking key words and how they are used in social media (Geraint, 2014).

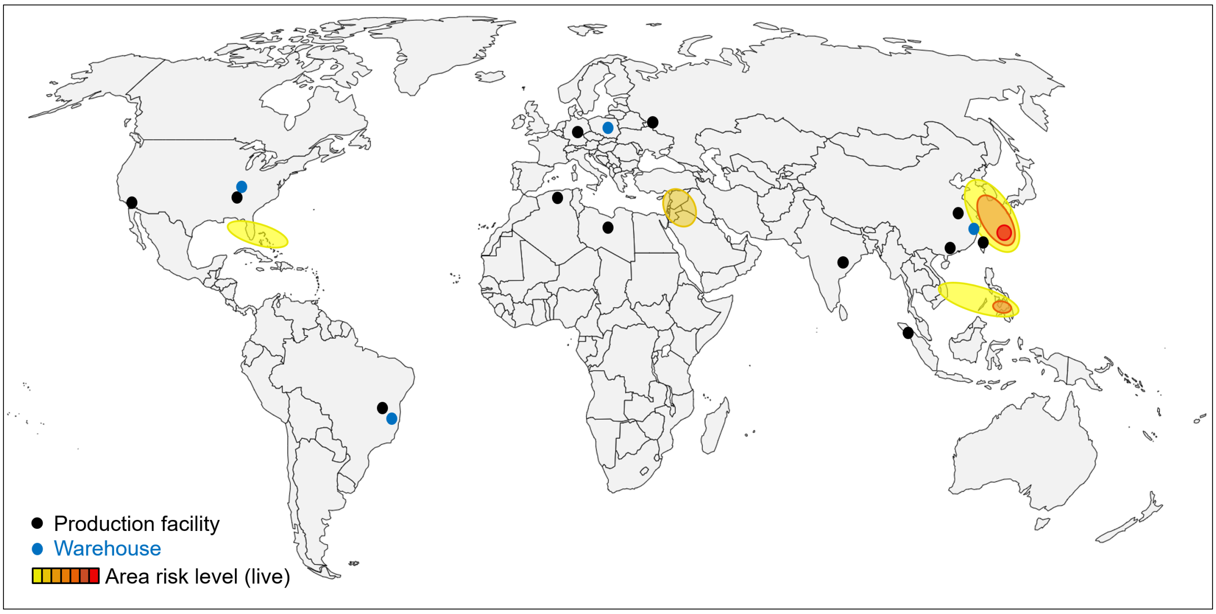


Figure 4.11: Illustration of a fictitious geographic analytics tool

Quantifying and prioritizing risk

To quantify and prioritize risks is often difficult due to the large number of unknown risks that are impossible to estimate in terms of their likelihood of occurrence and business impact. However, this fact is often disregarded and many companies are still using this traditional prioritization method (Geraint, 2014). Geraint (2014) describes a new way of prioritizing risk areas by disregarding the likelihood of an disruption occurring and instead focusing on the effect it would have on the supply chain if a supplier site were to be disrupted. By estimating the impact the disruption would have on sales per time unit and how long it would take for the supplier to recover, the financial impact can be estimated. By doing this, the most vulnerable nodes in the supply chain can be identified and the risks can be mitigated. An extension of this method, used by Ford Motor Company (Simchi-Levi et al., 2015), is described in section 4.2.2.

Mitigating risk and speeding recovery

When the segmentation is in place the most popular mitigation strategy, according to Geraint (2014), is to use active inventory tracking and dual sourcing. However, when using dual sourcing it is important to make sure that the suppliers are not using the same sub-tier suppliers. It can often be more efficient to consolidate volumes and negotiate with the current supplier to open multiple production facilities instead. Geraint (2014) argues that all companies, no matter how proactive, will suffer from disruptions from time to time. To minimize the damage it is important to have a business continuity plan and regularly assess the most crucial nodes in the supply chain.

5

Case description: Aptiv

This chapter presents relevant background information about the case company Aptiv. Moreover, an overview of the sourcing and supplier selection process used by the purchasing department today is presented. Emphasis of the chapter is on Aptiv's risk assessment procedure and its intermediate steps. Lastly, Aptiv's operative approach for monitoring supplier risk and performance using supplier scorecards is presented.

5.1 Company background

Aptiv is a global technology company providing end-to-end solutions for smart vehicle architecture and smart mobility solutions to many of the world's largest automotive manufacturers. Worldwide Aptiv employs more than 147 000 people spread out across the globe at more than 100 manufacturing sites and 15 major technical centers. Primarily Aptiv operates within two different business segments: (1) Advanced Safety & User Experience and (2) Signal & Power Solutions.

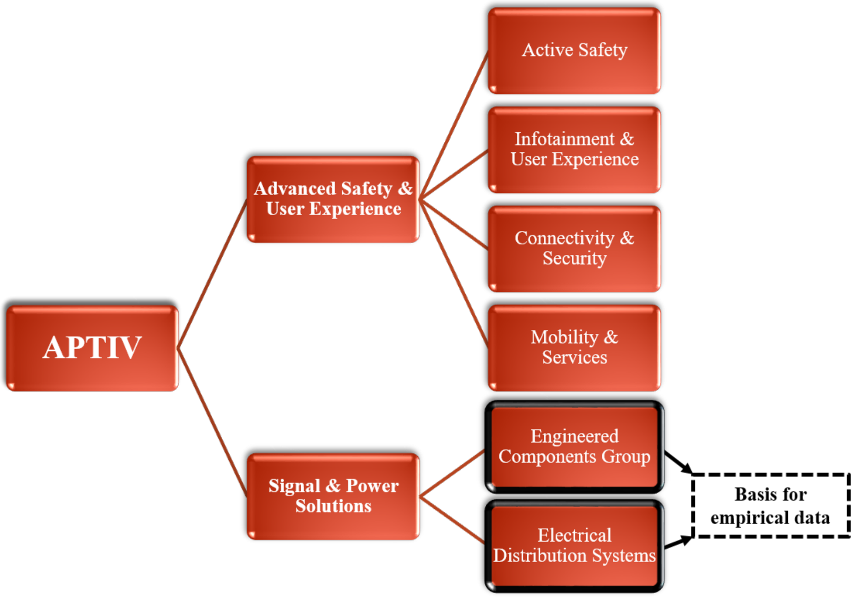


Figure 5.1: Aptiv organizational chart and primary business segments.

The business segment *Advanced Safety & User Experience* is comprised of four subsegments: (1) Active Safety, (2) Infotainment & User Experience, (3) Connectivity & Security and (4) Mobility & Services. These business lines offer complete hardware and software solutions within fields such as advanced driver-assistance systems (ADAS), autonomous vehicles, infotainment systems, connectivity solutions and various mobility services.

Signal & Power Solutions is comprised of two subsegments: (1) Engineered Components Group and (2) Electrical Distribution Systems. These two business lines (ECG and EDS) supplies the complete nervous system of the vehicle by providing complete design, manufacturing and assembly of the vehicle's electrical architecture. The empirical findings presented in this report were gathered primarily by interviewing respondents from these two business segments, and hence form the basis of this research.

Engineered Components Group (ECG) provides in-vehicle electronics, such as electrical centers, terminals, connectivity solutions, connectors, housings and seals among others. Additionally, via Aptiv's subsidiary HellermannTyton, ECG provides solutions for application tooling, cable protection, insulation and electrical installation. *Electrical Distribution Systems* (EDS) provides complete solutions for in-vehicle wiring assemblies, wire harnesses and a full range of electrical cables, including battery cables, antenna cables, USB cables, data cables and high voltage cables.

5.2 Sourcing and risk assessment process

This section presents an overview of the sourcing process used at Aptiv today, ranging from the first step where an OEM signs Aptiv as a supplier and awards them the business, to the last step where Aptiv selects and contracts their own suppliers. The description aims to provide some context for when and how the risk assessment is performed and how it is integrated within the sourcing process. The risk assessment process consist of two primary stages (Stage 0 & Stage A) with two additional stages (Stage B & Stage C) which are used when sourcing for new development components.

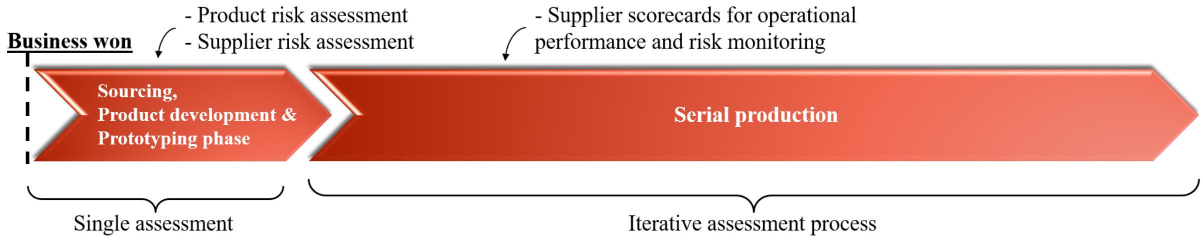


Figure 5.2: Simplified illustration of primary risk assessment activities.

The sourcing process and the primary risk assessment stages, as described by the interviewed managers at the firm and in internal documents, are presented below:

1. **Business won**
   OEM awards the business to Aptiv.

2. **Sourcing request submitted**
   Business requirement owner submits a sourcing request in an internal database.

3. **Bill of material received**
   Purchasing department is notified about the contract and are provided with a bill of material (BOM).

4. **Supplier bid list**
   Purchasing department creates a bid list based off an internal panel of approved suppliers. These are suppliers with whom Aptiv have worked before, and whom comply with the General Terms and Conditions, such as having payment and delivery terms set as well as having specific quality certifications (ISO9001 & IATF16949). These approved suppliers vary with regard to profitability.

5. **Risk Assessment Stage 0 - Product focus**

   In Stage 0 a risk assessment is performed focusing on identifying risks and requirements associated with a specific part/product. Such factors include: customer required certifications (ISO/IATF), whether it's a carryover or new design, part print readiness, program timing requirements, safety critical & legal considerations and tooling accessibility. Explained in more depth in section 5.2.1.

6. **Supplier contact and request for quotation**
   The purchasing department then establishes contact with suppliers, sends out request for quotations (RFQs), ensures available capacity and makes sure suppliers can meet production requirements during the lifetime of the project.

7. **Bid list evaluation**
   Supplier quotes are then analyzed and prioritized based on factors such as cost, quality & delivery performance, technological level and the supplier's localization.

8. **Risk Assessment Stage A - Supplier focus**

   Risk assessment Stage A consists of mapping risks related to specific suppliers. Factors under consideration include: financial health of supplier, historical delivery and quality performance, available capacity, raw material availability, quality certificates (ISO/IATF), geographic risk, supplier's plans to expand operations, PPAP and availability of union contracts. Explained in more depth in section 5.2.1.

9. **Supplier negotiation**
   Purchasing department then negotiates contract specific terms, such as price, minimum order quantities (MOQs) and delivery plans with the suppliers. Additional conditions are normally agreed upon in previous agreements. If the business award is particularly big, all contractual conditions are negotiated, including payment terms, incoterms and any other logistic uplifts.

10. **Supplier nomination**
    A supplier is nominated based on the risk assessment and overall cost optimization. If the requested part is not approved by the OEM, either the supplier or Aptiv (depending on the category, part and process), has to obtain the OEMs approval before the business can be awarded by Aptiv to the supplier.

11. **Supplier selection and sourcing request approval**
    Supplier nomination is reviewed internally and if the nomination is approved the business is awarded to the supplier.

5.2.1 Risk assessment

The risk assessment procedure, its key components, phases and what risk indicators are being evaluated are presented in this section. The data presented is based on the Excel-file currently used to conduct the risk assessment at Aptiv today, combined with additional insights provided by interviewees working with risk assessment on a daily basis. The authors combined interpretation of the studied documents and the interviews is presented in the following subsections.

Stage 0: Pre-sourcing product evaluation

Risk assessment stage 0 is performed prior to establishing contact with suppliers and focuses on mapping risks associated with a specific part/product. The evaluated risk categories are all rated using a numerical value between either 0-6 or 0-8. Where 0 means low risk and 6 or 8 means high risk.

A selection of the risk categories and product requirements that are evaluated during stage 0 are:

- **Customer requirements and expectations:**
  Including required/expected supplier certifications (ISO14001, ISO9001/IATF16949) and any design specific requirements appointed by the customer.
- **Design control:**
  Division of design responsibilities between Aptiv and their suppliers.
- **New or carryover design:**
  Is the part design new to Aptiv and/or the OEM or is it already being produced and is available on the market.
- **Part print readiness:**
  Availability or lack of approved and released part prints.
- **Program timing requirements:**
  Available time to complete all design, validation, sourcing, tool build, PPAP and production ramp-up requirements.
- **Safety critical & legal requirements:**
  The need for perfect reliability of the product and if it is subject to any legal requirements.
- **Tooling accessibility:**
  Potential to use existing tooling or if new tools and manufacturing processes need to be developed.

Stage A: Supplier risk assessment

During stage A the risk assessment is focused on the suppliers and their ability to deliver according to expectations. The risk indicators evaluated are all focusing on assessing the risks associated with specific suppliers, with focus on minimizing the total cost of sourcing and risk of disruption. A selection of the risk areas evaluated in stage A are:

- **Supplier approval:**
  Whether or not a supplier is known to Aptiv and have been approved previously.
- **Financial health of supplier:**
  Covers the the financial situation of the supplier and the region where the supplier operates.
- **Customer directed supplier:**
  Whether a supplier is appointed by the OEM or if Aptiv can select freely.
- **Supplier's historical performance:**
  Historical quality and delivery performance, such as defect units and commonality of operational disruptions. Also includes frequency of problem cases (PCs) and ease of problem resolution.
- **Available capacity:**
  Available manufacturing capacity and accessibility to tooling.
- **Workforce availability:**
  Supplier's accessibility to required workforce.
- **Raw material availability:**
  Ease of accessing the required raw material.
- **Geographic risk:**
  Low/high risk country, tariffs, trade barriers and procurement risk.
- **Quality certificates:**
  Supplier has already obtained required certificates (ISO14001, ISO9001/IATF16949), or if a plan to become certified has been put in place.
- **Plan to expand operations:**
  Supplier's plans to expand/retract their operations, such as expected future hiring requirements and plans to build additional manufacturing facilities.
- **PPAP[1] approval and timing:**
  Potential issues/delays for the supplier to meet the PPAP due date.
- **Supplier union contracts:**
  Type and length of union contract or the lack of contract.
- **Supplier's sub-tier dependence:**
  Supplier's level of dependence on sub-tier suppliers.
- **Supplier's technology level:**
  Supplier's access to and familiarity with the technology required for manufacturing.
- **Supplier Run@Rate:**
  If Run@Rate plans meet capacity and time requirements.

[1]Production part approval process (PPAP) is a tool used to ensure that the quality required by the customers is delivered (Hermans & Liu, 2013; Doshi & Desai, 2016). PPAP aims to ensure that specifications are understood by the supplier and that manufacturing has the capabilities needed to deliver sufficient volume of products/components with an acceptable quality within the time frame (Hermans & Liu, 2013; Doshi & Desai, 2016).

Stage B & C: Product quality and supplier capabilities assessment

Stage B and C of the risk assessment is focused on assessing the supplier's capability to produce the requested component at the desired quality level and production volumes. The assessment is primarily used for new product developments without carryover of processes and technology. New product development without any carryover is relatively rare within the automotive industry due to the requirement from OEMs that new components need to undergo lengthy testing periods (∼1 year). When it happens however, the suppliers are requested to present:

- Advanced product quality planning (APQP)
- Tooling and equipment planning
- Production trials and Run@Rate tests
- Prototype developments
- Approved PPAP

If the product is known or it has carryover processes and technology the focus is primarily to collect the approved PPAP. The importance of this stage is to assess the PPAP plan and result, that is, if it is approved with or without issues and the magnitude of the issues.

5.3 Supplier performance scorecards

One of the components Aptiv use for monitoring supplier performance on a daily basis is supplier scorecards. These scorecards act as an evaluation tool for measuring operational performance of suppliers and hence allows for problems and risks to be identified, monitored and tracked. Categories under consideration include quality, cost, shipping and overall compliance. A selection of subcategories included in the scorecard evaluation include: number of problem cases, conformance to corrective actions, production spillage and response timing.

The premise of how the scorecards work is that once every month each factor included in the scorecard is assessed and assigned a numeric value. These values, given certain severity thresholds and weight factors, sum up to an overall supplier performance score over the period. The overall supplier performance score (ranging from 0-100 where 100 is the best) is then saved in an internal database. Over time, as additional scores are registered, trends in supplier performance can be identified as depicted in Figure 5.3.

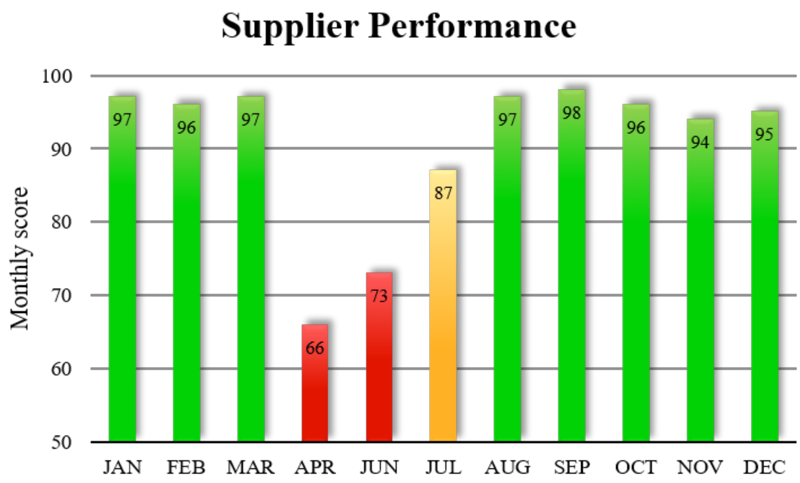


Figure 5.3: Supplier performance monitoring using supplier scorecards.

The scorecard values are classified either as *'Good'* (>90), *'Needs monitoring'* (80-90) or *'Corrective action needed'* (<80). Illustrated in Figure 5.3 by assigning either green, yellow or red to each monthly score. Green indicating supplier performance is as expected, yellow indicating minor issues requiring monitoring and red indicating severe issues requiring immediate corrective actions to be put in place.

Scorecards for all suppliers are readily available in an internal database and does not only allow for monthly performance monitoring, but also assist in the supplier selection process when contracting suppliers for new businesses.

6
Empirical Findings

This chapter presents the empirical findings gathered through interviews with managers at the focal company Aptiv, as well as from interviews with managers from six other technology manufacturing companies. The presented data, as described by the interviewees, include: (1) primary supply chain risk areas faced today, (2) a set of proposed mitigation strategies and (3) potential tools/strategies to better manage supply risk in the future.

Chapter overview

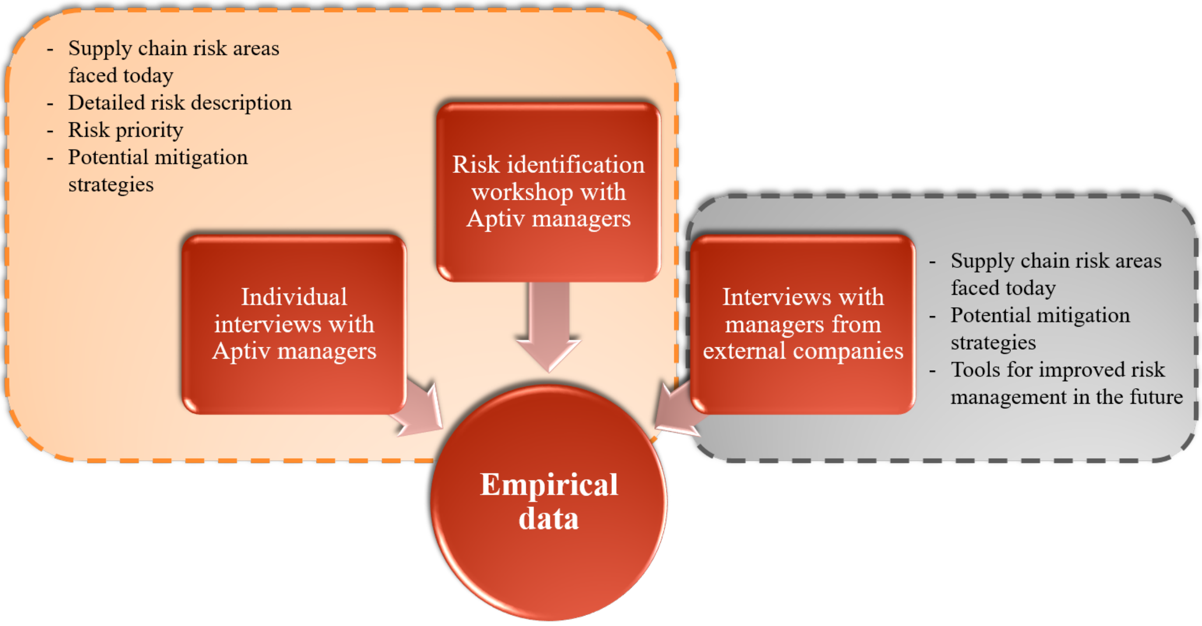


Figure 6.1: Overview of the primary empirical data sources.

Figure 6.1 illustrates the three primary empirical data sources and presents what type of data were retrieved from each source. The findings are presented in three separate tables throughout the remainder of this section and are further analyzed in chapter 7.

Subsection 6.1 covers the individual Aptiv respondents as well as the data retrieved through a workshop with a cross-functional focus group. Subsection 6.2 covers the findings from external companies. Due to anonymity requirements, no explicit titles and/or responsibilities of individual interviewees is presented. As for the external companies, fictional names have been used in order to maintain full anonymity.

Each of the two subsections concludes with a summary of the most important supply chain risk areas as perceived by the interviewees. The summary is based on response frequency, i.e. how often a risk area was lifted by different respondents, combined with a risk prioritization performed by the cross-functional focus group.

6.1 Respondents at Aptiv

Table 6.1: Risk areas and mitigation strategies brought up by Aptiv managers.

Interviewees	Primary supply chain risk areas	Mitigation strategies
Quality manager	1) Narrow design specifications provided by OEM enforces Aptiv to source from a single supplier. Aptiv's inability to change these suppliers is making Aptiv too dependent on them. 2) Insufficient supplier capacity when sourcing components with limited supply availability. 3) Long-term sourcing contracts of a specified component are creating obsoletes when design changes occur.	1) Either find a supplier that is willing to invest in the tools needed to produce the specified component or negotiate with OEM to revise the specification. 2) Find new suppliers to make copies of the components with supply shortage. 3) Improved communication between departments, such as involving engineering more in sourcing decisions.
Purchasing manager	1) Engineering changes made once sourcing has started and the contracts and negotiation are completed. 2) Customer directed components through narrow design specifications. 3) Single sourcing of components due to price focus or lack of alternative suppliers. 4) Insufficient supplier capacity. 5) Force majeure, such as plant accidents and other major disruptions. 6) Suppliers not allowing audits due to their reluctance to share IP.	1) Introducing composite drawings, meaning for a pre-negotiated additional fee minor design changes can be made. 3) Select components with dual sourcing alternatives
Group leader for technical project managers	1) Mismatching lead time requirements when sourcing sub-assemblies. 2) Late design changes requested by the OEM.	1) Increased standardization and product modularity. 2) Introducing virtual prototyping, composite drawings and increased standardization and modularity.

Program manager	1) Cost based purchasing incentives which increases the risk appetite of the suppliers. 2) Lack of pre-information and early indicators of risks associated with new suppliers. 3) Suppliers leaving the automotive industry to increase their profits. 4) Resource scarcity.	1) Introducing cross-functional purchasing teams or assessing the total cost of sourcing instead of price per part. 2) Improved routines for performing an initial supplier risk assessment. 4) Increased design for purchasing focus in order to avoid scarce materials.
Engineering manager 1, Engineering manager 2	1) Certain suppliers are overloaded and can not produce the required volumes which causes delays. 2) Cost focus in purchasing. 3) Component and tooling experts leaving the suppliers for other companies and countries. 4) Multiple problem cases open at supplier at the same time. Priority of problem resolution shared among the supplier's customers.	1) Use multiple sourcing in order to secure supply. Assess the supplier capacity plan before placing orders. Introduce cross-functional purchasing teams to be able to better assess the suppliers and what is needed of them. Perform business impact analyses in order to estimate the consequences of late deliveries. 2) Use cross-functional purchasing teams to better assess total cost of sourcing. 3) Assess the suppliers future capacity and workforce plans in order to secure on-time deliveries.
Category manager 1, Category manager 2	1) Some suppliers are negotiating directly with the OEM, after which the OEM writes the specifications such that Aptiv is forced to source from them. When quality issues occur, OEM places the responsibility on Aptiv. 2) OEM's reluctance to change components is limiting the availability of supply options. 3) Fluctuations in raw material prices.	3) Increased focus on design for purchasing.

Focus group

Table 6.2: Risk areas brought up by the focus group.

Risk category	**Risk areas faced by Aptiv today**
Quality	- Sourcing from PPAP self-certified suppliers. - Late PPAP approvals. - Late design changes requested by the OEM, increasing the complexity to maintain a high quality level.
Supplier dependence	* - Lack of competence for challenging suppliers. - Inability to change supply source.
Information systems	* - Lack of pre-information of the consequences (increased risk) a new/different supplier brings. - Insufficient collaboration with suppliers. - Lack of communication between purchasing and other business units. - Suppliers selected with a cost focus without communicating the new and potentially increased risks to other project teams.
Forecast	* - Design changes requested in a late stage causing obsoletes. - Late forecast updates in ordering systems. - Mismatch between customer's lead time requirements and supplier's lead time. - Acting on preliminary OEM data to cope with deadlines.
Supplier capacity	- Overloaded suppliers with insufficient manufacturing capacity.
Financial	- Supplier price adjustments can not be pushed downstream to OEM/end customer. - Diverse supplier base subject to exchange rate fluctuations.
Procurement	* - Sourcing based on preliminary forecasts due to long lead times for subassemblies. - Lack of available suppliers due to narrow design specifications provided by OEMs. - Single sourced components. - Cost based purchasing incentives. - Sourcing of flagged high-risk components due to price focus. - Long-term sourcing contracts leading to obsoletes when engineering changes occur. - OEM supplier approval required.

Note: * indicates that the risk area was rated high priority.

Summary

This section highlights the most important supply chain risk areas faced today, as perceived by interviewed managers at the focal firm. Based partly on the frequency of which risk areas were brought up interviewees, and on the risk prioritization made by the focus group.

Figure 6.2 displays the frequency of the most commonly brought up risk areas by individual respondents from the focal firm in orange. Prioritized risk areas also brought up by the cross-functional focus group is marked in white.

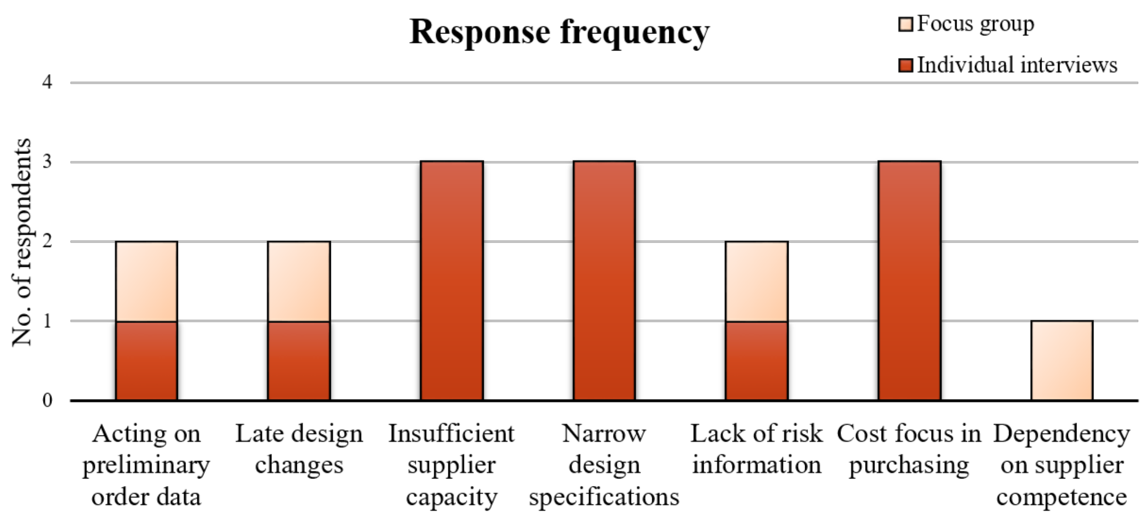


Figure 6.2: Interview response frequency and risk prioritization made by the focus group.

6.2 Respondents from external companies

This section presents the data retrieved by interviewing managers from six external manufacturing companies. Primarily, the respondents were from business functions such as strategic purchasing, project management and supply chain management. The presented data include (1) supply chain risk areas, (2) primary risk mitigation strategies and (3) potential tools to use for improved supply chain risk management in the future.

The risk areas presented are those considered most critical by the interviewed managers. The same applies for the presented risk mitigation strategies, which are a collection of the most significant strategies as brought up by each individual respondent. Risk areas in Table 6.3 marked with an * are expected to increase in significance in the coming years.

Table 6.3: Empirical data retrieved through interviews with external companies.

Industry	Supply chain risk areas	Risk mitigation strategies	Future improvement actions
Networking and telecommunication manufacturer	* - Supply and material availability. * - Suppliers leaving the industry in favour of more profitable alternatives. * - Partnering with unknown suppliers. * - Cyber and IP security. * - Shifting low-cost countries. * - Natural disasters * - Baring the responsibility for supplier's actions. * - Increased complexity in handling environmentally hazard chemicals at suppliers in low cost countries. * - Global political tension and introduction of trade barriers.	- Multi-sourcing. - Supplier audits. - Buffer inventories. - Code of conduct. - Whistleblower function. - Long-term sourcing contracts. - Supplier performance scorecards. - Early supplier involvement.	- Utilizing real time data from online map services to detect anomalies (force majeure, conflicts, major accidents, etc.). Once detected, immediately initiate contact with suppliers in the region. - Using AI to scan social media and news feeds to detect potential supply risks. Such as detecting upcoming labour strikes or political turmoil in the region.

Space technology manufacturer	- Customer enforced suppliers. - Limited supply and material availability. * - Requirements for reduced time-to-market. - Rapid and severe loss of corporate goodwill if quality issues occur. * - Quality issues due to sourcing from new unknown suppliers. - Strict quality assurance requirements.	- Assisting suppliers with R&D. - On-site personnel. - Knowledge sharing workshops.	- Strategic partnerships with suppliers for sharing risk and building long-term relationships. - Innovation hubs, where suppliers are invited to share knowledge, participate in product development and create added value for both sides.
Electrical equipment manufacturer	* - Reduced availability of materials and suppliers due to increased competition from other industries (especially automotive). * - Introduction of new technologies and previously unknown suppliers. * - Fake components entering the market. - Conflict minerals (3TGs). * - Risk of becoming blacklisted if sourcing from or exporting to countries subject to global sanctions. * - Open source requirements for software. * - Cyber and IP security. - Social sustainability.	- Multi-sourcing. - Buffer inventories. - On-site supplier audits. - Supplier self-assessments. - Code of conduct.	- Software called BlackDuck for identifying keywords and/or phrases in incoming source code that may infringe copyright claims. Can also be used for tracing source code origin before shipping to customers in countries subject to sanctions.
MedTech company	* - Reduced time-to-market requirements. - Maintaining high quality when sourcing for mass production. - Customer requirements differing between regions which requires many product variants. * - Shortened product life-cycles. - Ever-changing country specific regulations. - Patent restrictions.	- Process validation instead of product validation. - Flexible manufacturing.	

Technology manufacturing company	* - Supply chain disruptions (financial distress, failure in manufacturing/logistics, natural disasters). * - Supply chain CSR (child labor, frauds, bribery, pollution). * - Brand protection (leakage of sensitive data and IP). - Increased supply chain complexity and delivery risk due to a globalized and geographically spread out supplier base.	- Multi-sourcing. - Partnerships with suppliers. - Supplier auditing (including CSR aspects). - Tier 2+ supplier risk assessments. - Confidentiality agreements.	
Climate solutions manufacturer	* - Supply and material availability. - Competition for securing supplier manufacturing capacity of critical components. * - Cyber security. * - Increased regulatory uncertainty. - Availability and relocation of workforce. * - Shortened product life cycles requiring reduced time-to-market. * - Natural disasters disrupting the supply chain. * - Political tensions resulting in new trade barriers.	- Multi-sourcing. - Supplier scorecards. - Supplier risk assessments. - Regional risk assessments. - Product risk assessments.	- Tools for better risk assessment of high tier suppliers (Tier >1). Limited transparency and availability of data make this difficult today. - Systematic and structured risk assessment procedures. Gut-feel is too unreliable in today's complex and globalized supply chains.

Note: * indicates that the risk area is/will be increasing according to the respondent.

Summary

This section highlights the most important supply chain risk areas faced today, as perceived by the six interviewed managers at the companies listed in Table 6.3. These figures are based on the frequency of which risk areas were brought up by the interviewees.

In Figure 6.3 all crucial risk areas brought up by at least two of the external companies are illustrated in descending order.

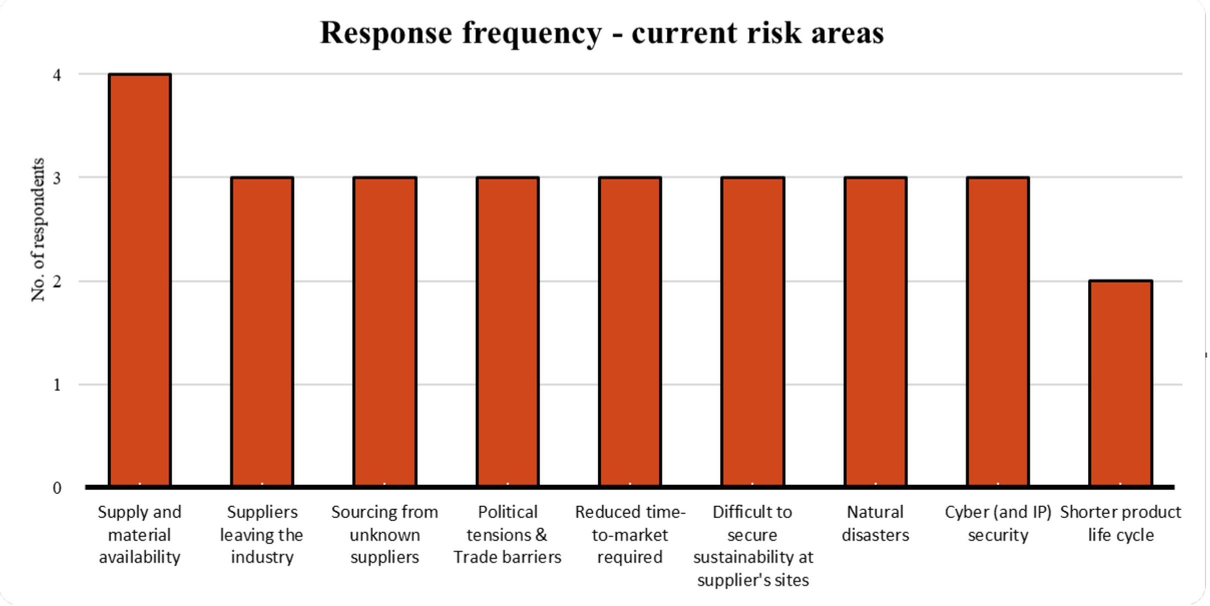


Figure 6.3: Interview response frequency of current supply risk areas.

In Figure 6.4 the risk areas that, according to the respondents at the external companies, are expected to increase are illustrated in descending order.

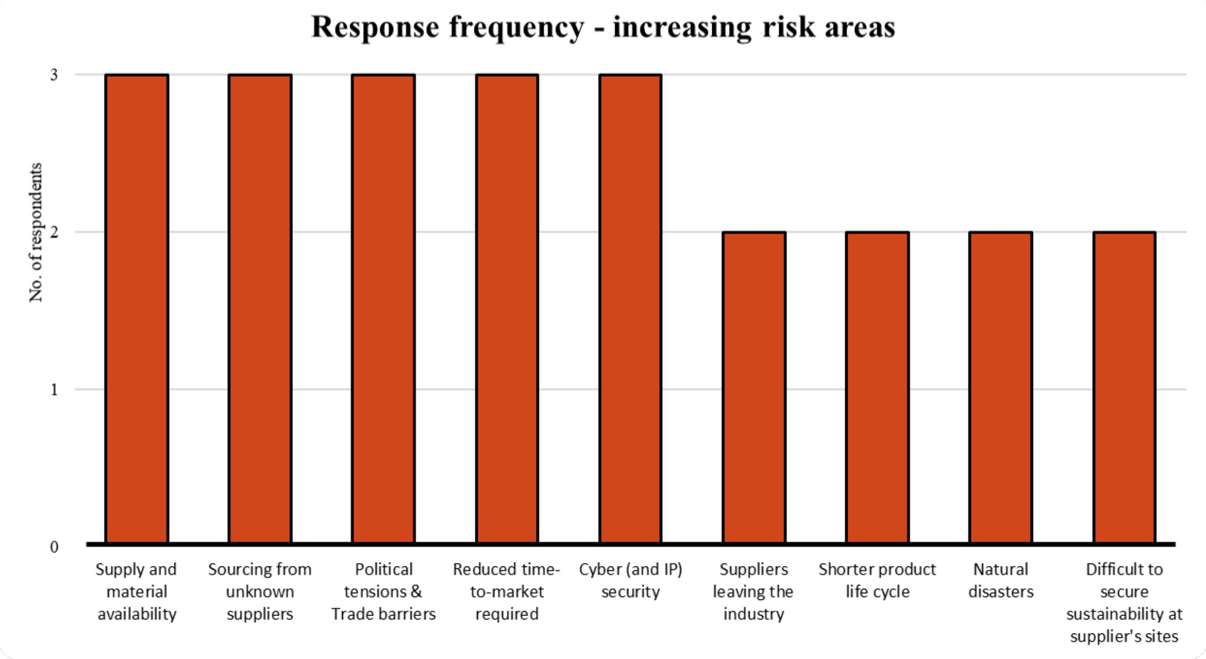


Figure 6.4: Interview response frequency of increasing supply risk areas.

6.3 Respondents from academia

Table 6.4: Empirical data retrieved through interviews with external companies.

Title and field of research	**Supply chain risk areas**	**Risk mitigation strategies**	**Future improvement actions**
Postdoctoral researcher - Logistics and sustainable SCM	*1) Data and IP security. *2) Servitization is transforming the business model for OEMs. *3) Political and economic risks especially concerning *'unknown unknowns'*[1]. *4) Social and environmental sustainability.	1) Usage of blockchain strategies. 2) Crucial to change the company and re-sellers culture in order to succeed with the business model transformation. 3) It is per definition hard to predict *'unknown unknowns'*. The only way to handle these risks is by having established re-routing alternatives for both supply and production. 4) Authorization and continuous review of suppliers. This however, is time-consuming and expensive. Another option is to use digital diaries for sub-tier suppliers as a whistle blower function.	- Digital diaries for sub-tier suppliers functioning as a whistleblower system. The digital diaries are analyzed by AI trained to search for key words and phrases. If many issues are reported within the same area actions can be taken to prevent issues from spreading. - Use blockchain to create digital trails of records of innovation processes. Blockchain certificates enable proof of existence and ownership and information could be kept private.

Note: * indicates that the risk area is/will be increasing according to the respondent.

[1] *'Unknown unknowns'* are the events where the occurrence and the potential impact are both unknown to the organization (Seong Dae, 2012).

7

Analysis and Discussion

This chapter presents the authors analysis of how the empirical data gathered from the qualitative interviews correlate. Supply side risk areas as perceived by Aptiv managers are summarized and categorized, and a selection of high priority risk areas are described in more depth. These risks are then mapped to input retrieved from external companies and commonalities are then derived and presented. After that a four-step framework for supply risk assessment is presented. This is followed by an overview of potential new tools to use for improved proactive risk management and strategies for proactive supply risk management. Lastly, a set of three proof-of-concept supply risk dashboards developed by the authors are presented.

7.1 Current supply risk areas

In this section an analysis of which risk areas are most critical for the automotive and technology industry is conducted. In the first part the major supply risk areas faced by Aptiv today is presented. In the second part the major risks identified through interviews with the external companies are described and compared to the risk areas presented in the first section. The last part summarizes which risk areas are to be considered particularly important within technology supply chains.

7.1.1 Supply risk areas faced by Aptiv

The specific risk areas brought up by respondents from the focal firm have been grouped into eight different risk categories which are presented in Table 7.1. These categories were selected by the authors as a mean to aggregate multiple risks into single categories. The categorization used is partly based on the risk categorization provided by Blackhurst et al. (2008).

A selection of the identified risk areas were marked *'high priority'* by a focus group consisting of program, purchasing and engineering managers from the firm, all of which are explained in more depth throughout the remainder of this section.

Table 7.1: Risk areas found throughout the empirical research.

Risk category	**Risk areas faced by Aptiv today**
Quality	- Sourcing from PPAP self-certified suppliers. - Late PPAP approvals. - Reduced product quality as an effect when selecting more profitable suppliers. *- Late design changes requested by the OEM, increasing the complexity to maintain a high quality level. (7.1.1.2) - Changing components could have multiple implications for the vehicle's systems, hence OEMs often disapproves changing components and/or suppliers.
Supplier dependence	*- Lack of competence for challenging suppliers. (7.1.1.7) - Inability to change supply source.
Information systems	- Insufficient collaboration with suppliers. *- Lack of communication between purchasing and other business units. (7.1.1.5) *- Suppliers selected with a cost focus without communicating the new and potentially increased risks to other project teams. (7.1.1.5) *- Lack of pre-information of the consequences (increased risk) a new/different supplier brings. (7.1.1.5)
Forecast	- Late forecast updates in ordering systems. *- Design changes requested in a late stage causing obsoletes. (7.1.1.2) *- Mismatch between customer's lead time requirements and supplier's lead time. (7.1.1.1) *- Acting on preliminary OEM data to cope with deadlines. (7.1.1.1)
Intellectual property	- Suppliers reluctant to share proprietary knowledge. - Supplier not permitting audits due to unwillingness to share IP.
Disruptions/ disasters	- Force majeure. - Plant accidents. - Labor disruptions.
Supplier capacity	*- Overloaded suppliers with insufficient manufacturing capacity. (7.1.1.3) *- Limited accessibility to workforce. (7.1.1.3) - Multiple problem cases open at supplier at the same time. Priority of problem resolution shared among the supplier's customers. - Insufficient supplier capacity within sourcing of components with limited access.
Financial	- Supplier price adjustments can not be pushed downstream to OEM/end customer. - Diverse supplier base subject to exchange rate fluctuations.
Procurement	*- Sourcing based on preliminary forecasts due to long lead times for subassemblies. (7.1.1.1) *- Lack of available suppliers due to narrow design specifications provided by OEMs. (7.1.1.4) - Single sourced components. *- Cost based purchasing incentives. (7.1.1.6) *- Sourcing of flagged high-risk components due to price focus. (7.1.1.6) - Long term sourcing contracts leading to obsoletes when engineering changes occur. - OEM supplier approval required.

	*- Engineering changes made when sourcing has started and the contracts and negotiation are completed. (7.1.1.2) - Suppliers leaving the automotive industry to increase their profits. - Resource scarcity. - Fluctuations in raw material prices.

Note: * indicates prioritized risk areas and are covered in the coming subsections.

7.1.1.1 Acting on preliminary order data due to mismatching supplier and customer lead time requirements

Problem background

Due to mismatching lead time requirements between OEM's and certain suppliers, orders sometimes have to be placed based on preliminary forecast data provided by the OEM. This was exemplified by interviewed managers at the focal firm as is presented in Figure 7.1.

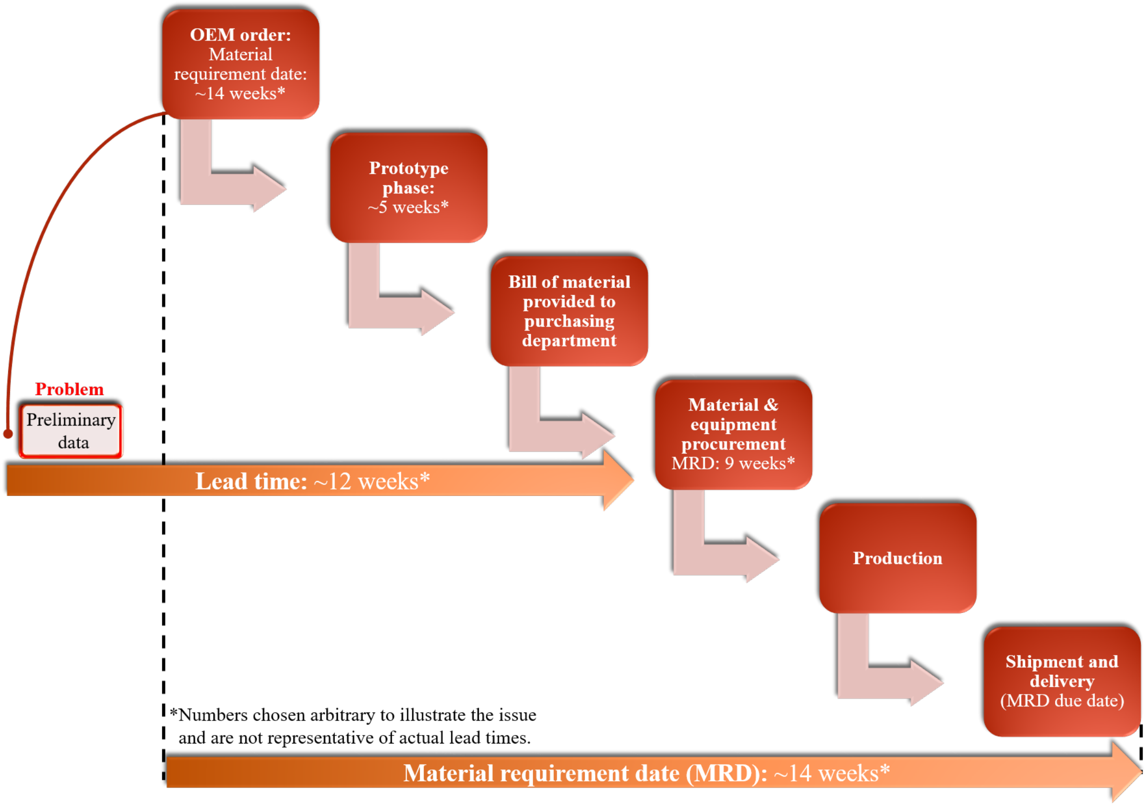


Figure 7.1: The issue of mismatching lead time requirements between suppliers and OEMs.

Initially the OEM places an order with a specified Material Requirement Date (MRD). Then prototypes are developed internally before a bill of material (BOM) is provided to the purchasing department. At the time the BOM reaches purchasing, the lead time for sourcing material and equipment sometimes exceeds that of the remaining time to meet the MRD. This forces Aptiv to act on preliminary data provided by the OEM in order to fulfill the order on time. Sourcing based on preliminary data is deemed risky as it can result in a substantial amount of obsolete goods without a clear distinction of who is financially responsible.

Proposed improvement strategies
One potential improvement strategy for the mismatching lead times, as suggested by Aptiv managers, is to speed up the prototyping phases by using virtual prototyping. Initiatives to implement virtual prototyping have been attempted in the past without the desired effect. It is however considered being an option to potentially speed up the development process significantly, but is currently in its infant stages and is not considered viable as a replacement option to physical prototypes.

Increased standardization, design postponement and modularity of components/products are other proposed strategies which potentially can decrease the lead time requirements. These strategies are however increasingly difficult to implement in an automotive environment that is rapidly changing where a lot of new technologies are being introduced.

7.1.1.2 Late design changes requested by the OEM resulting in obsolete components

Problem background
To explain this issue, a high-level overview of Aptiv's product development process is required. This process consists of four different phases: (1) Electrical prototype, (2) Verification prototype, (3) Tool tryout and (4) Pre-production. These phases are executed before a product/component is sent to serial production at any of Aptiv's production facilities. An overview of the different phases is presented below:

- ***(1) Electrical prototype:*** Building an electrical prototype, for example a complete set of wiring harnesses, connectors and terminals to be used for the in-vehicle electrical architecture. Focus is to test and verify the electrical functionality and the design requirements are often uncertain at this stage.
- ***(2) Verification prototype:*** Collaboration with the OEM, where an initial physical prototype of the car is built in order to test the components in a realistic manner. The component design is still uncertain at this stage.
- ***(3) Tool tryout:*** Manufacturing tools are developed and tested in an initial attempt to produce the product with the right quality at the right capacity. Some design changes might occur in this stage, however it is often too late sourcing new material, components or subassemblies sometimes resulting in the wrong design entering pre-production and serial production.
- ***(4) Pre-production:*** During pre-production the tools are multiplied and all components that will be used should have full PPAP-approval. This is the final phase before a component in sent into serial production.

One issue faced by Aptiv today is late design changes requested by the OEM in phase (3) and (4), which can lead to several problems, including: excessive obsolete goods with unclear division of financial responsibility, being forced to develop new prototypes, being forced to use expedited shipping and/or the worst case being forced to send an incorrect design into serial production. The problem with late design changes is visualized in Figure 7.2.

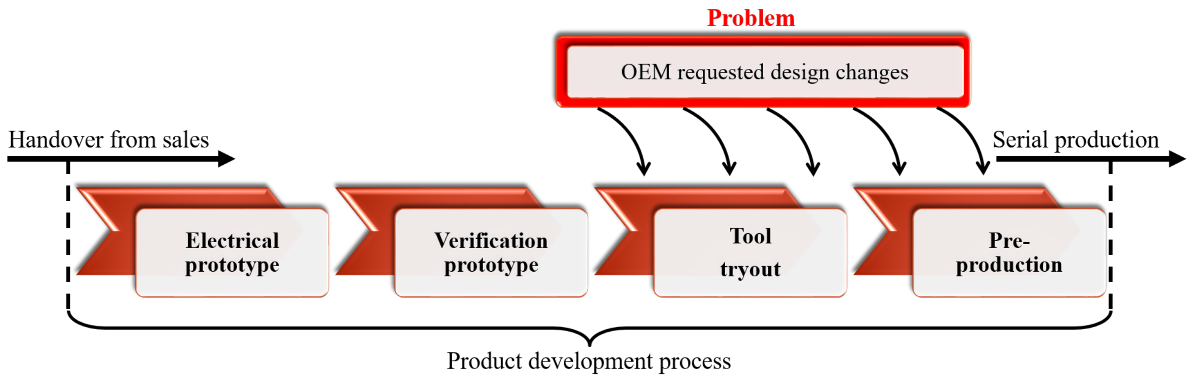


Figure 7.2: The issue of late design changes requested by the OEM

Proposed improvement strategies

A set of potential improvement strategies to cope with the issue were identified through interviews with Aptiv managers. A short term option, not deemed viable in the long term, is to use *'spot buying'* - essentially referring to using a faster sourcing process to meet immediate requirements (such as using expedited deliveries and skipping the RFQ → quotation process). Another option is to use *'composite drawings'*, referring to setting up an agreement with the supplier that allows sourcing components with different design specifications.

7.1.1.3 Insufficient supplier capacity

Problem background

That insufficient supplier capacity impose a large risk for Aptiv's supply chain was brought up by several of the interviewed respondents, some of whom described it as the largest risk for their department due to their lacking ability to influence the situation. The problem originates in suppliers' lacking capacity to manufacture what is required on time, causing delays when sourcing components for Aptiv's own products and tools. To make the issue even worse, there is a trend of qualified employees leaving the country of the suppliers at certain low-labour cost locations.

The incurred delivery delays is an escalating problem; the OEMs (Aptiv's customers) require shorter lead times due to the fast paced market and at the same time certain suppliers require longer lead times due to lack of capacity and workforce losses.

A major cause for this issue, according to Aptiv managers, is that the automotive industry has peaked in recent years with regard to production volumes, and its been difficult for suppliers to keep up with the market requirements. Moreover, suppliers are unwilling to scale up their production to meet the current demand because they are expecting a forthcoming recession. When the recession arrives they want to avoid having more excess capacity than what is necessary. This problem is illustrated in Figure 7.3

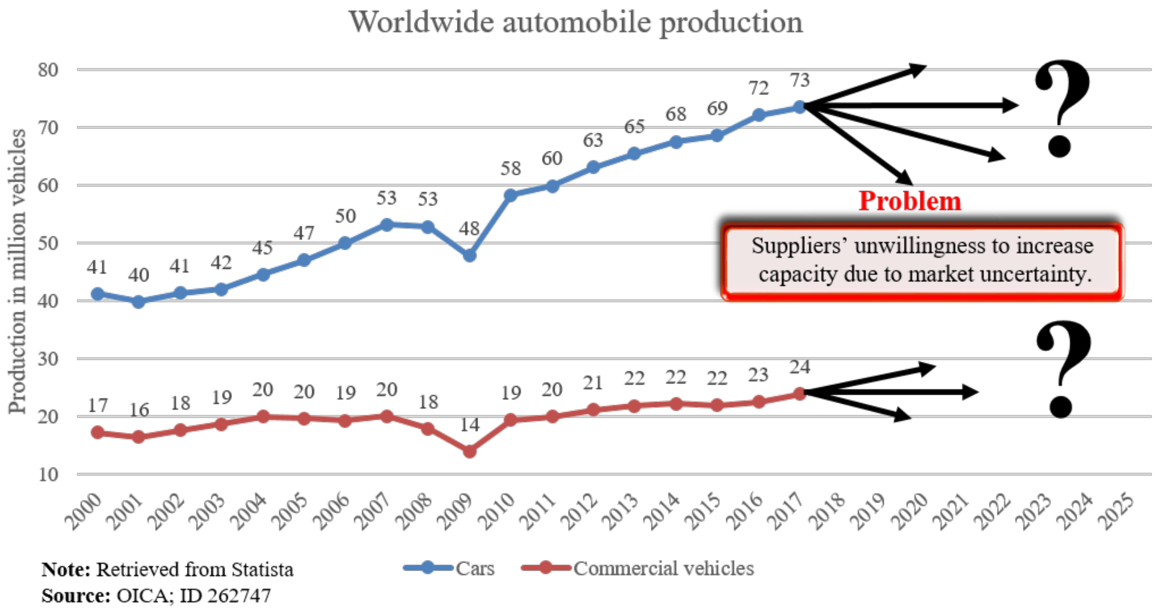


Figure 7.3: Illustration of why supplier capacity is an increasing issue within the automotive industry. Data retrieved from Statista (2018).

Proposed improvement strategies

Several suggestions for how to cope with the situation were identified. Firstly, in the instances where there is no shortage of suppliers, multiple sourcing could be used to a greater extent than what it is today. This of course increases immediate sourcing costs, but could reduce the overall total cost of sourcing if delivery delays could be mitigated. Another suggestion were to simply take future capacity plans of the suppliers into greater consideration when selecting suppliers.

Additionally, the importance of cross-functional decision making in purchasing and sourcing were emphasized. This would enable a total cost of sourcing perspective which, according to the interviewed managers, could solve many of the issues they are currently facing. For example, this could mean involving personnel from engineering and R&D in the sourcing decision to an greater extent.

A final proposition were for the purchasing department to start performing impact analyses specifically for identifying potential consequences and mitigation options when facing suppliers with insufficient capacity.

7.1.1.4 Narrow design specifications and customer designated suppliers

Problem background

Customer designated suppliers refer to any subsupplier appointed directly by the OEM, i.e. stating that if you want to be awarded the business by the OEM you have to use a specific supplier. For suppliers within the automotive industry, this is normally a good thing as the OEM assumes responsibility of that supplier and companies such as Aptiv are merely acting as middlemen. However, a recurring problem faced today is the OEMs ability to instead of appointing designated suppliers rather tend to write very narrow design specifications. This issue entails that automotive suppliers like Aptiv are constricted to a very limited amount of subsuppliers (sometimes only one), and are essentially being forced to select a supplier appointed by the OEM, without the safety net of the OEM assuming responsibility as is the case with customer designated suppliers.

The issue with these *'narrow specification enforced'* suppliers is that Aptiv has no to little say in the selection of these suppliers. Yet still have to bare the responsibility for their actions and any incurred quality problems or delivery delays. The interviewed managers described that a recurring problem is these supplier's refusal to listen to complaints made by Aptiv because they are aware that Aptiv is not in power to change to another supplier. When Aptiv instead brings up an issue with the OEM, the OEM responds that they have no responsibility for that supplier and that it is up to Aptiv to handle it. One interviewed manager, who encounters this problem daily, emphasized that in the cases where the issue with the supplier is capacity related, neither the OEM nor Aptiv has the power to improve the situation, and in these cases the OEM is often more willing to renegotiate the design specifications and which components are to be used.

The issue with *'narrow specification enforced'* suppliers is illustrated in Figure 7.4.

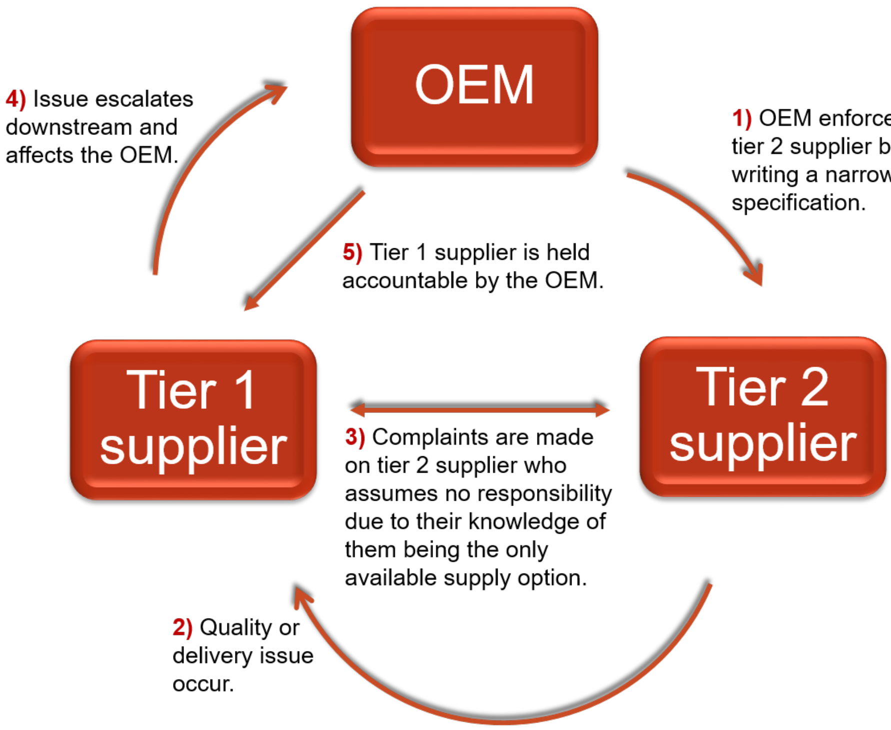


Figure 7.4: The issue of handling customer designated suppliers

Proposed improvement strategies

Two primary mitigation strategies were identified. The first being making the supply chain less dependent on these enforced suppliers. This could be done by finding either another supplier that produce a component fulfilling the customer specification or a supplier willing to invest in the tools needed to start producing the component. However, finding a supplier producing the exact same component is rarely an option.

The second strategy is to negotiate the selection of components with the OEM and convince them to select components with multiple suppliers in order to make their supply chain less vulnerable. This however, often has an impact on price, which is a reason as to why the OEM often dodge this discussion with their first tier suppliers.

7.1.1.5 Lack of risk related pre-information and information sharing between business units and projects

Problem background
One issue brought up by several of the interviewed managers at Aptiv is the lack of pre-information of the consequences that contracting a new/different supplier brings with regard to supply risk. For example, when a new supplier or a supplier that has been idle (not used by Aptiv recently), is awarded the business, the potentially increased risks with signing that supplier are difficult to estimate and are not communicated across business units and between projects successfully.

A more proactive risk management approach, based on improved pre-information regarding supplier specific risks, was identified as a key enabler in order to improve today's supply chain risk management capabilities.

Proposed improvement strategies
The risk assessment procedure used before selecting suppliers needs to assessed and potentially updated with additional metrics that would allow purchasers to catch early warning signals of potential risks within the supply base.

Interviewees also emphasized that additional efforts need to be put on analyzing supply risk on a daily basis, instead of relying on a snapshot risk assessment that is performed prior to commencing sourcing. This is done today partly by using supplier scorecards which are based on the frequency and severity of problem cases open at the suppliers (see section 5.3).

Both the risk assessment performed prior to sourcing, and the risks caught by using the supplier scorecards, needs to be communicated more effectively across business units and between projects. One proposed option to do so is by using a dashboard with critical risk KPIs related to different parts and/or components. This dashboard could be used as a decision support system by upper management or as a tool for conducting efficient cross-functional meetings.

7.1.1.6 Cost based purchasing incentives

Problem background
One issue brought up by several of the interviewed managers is the cost-based incentive structure present in today's purchasing organization. This drives purchasers to select the supplier that is quoting the lowest cost, without being able to predict the potential risks associated with their decision. This problem is illustrated in Figure 7.5.

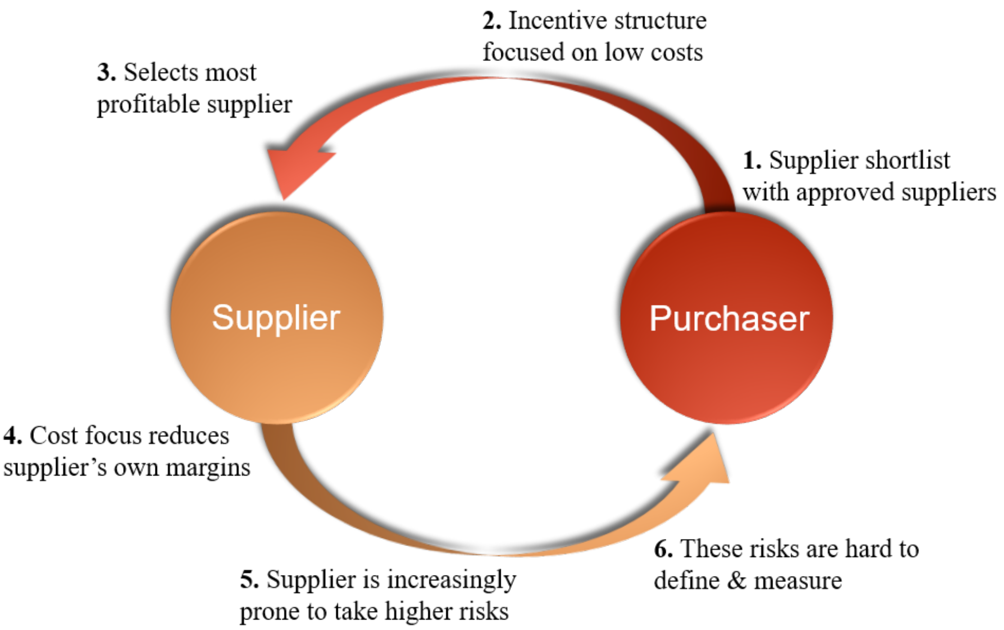


Figure 7.5: The destructive cycle of cost based incentive structures within purchasing.

According to managers at the firm, the cost focus within purchasing is considered particularly important in the automotive industry due to several reasons: (1) it's a low margin industry (average ∼7% EBIT margin for auto parts suppliers and ∼6% for OEMs (Parkin, Wilk, Hirsh, & Singh, 2017)), (2) the industry is subject to intense competition and (3) due to the inability to pass on increased raw material prices to the end consumer.

An additional illustration of how the cost-based incentive structure within purchasing impacts supply risk is presented in Figure 7.6, based on a description provided to the authors during the empirical research. Paraphrased by the authors below:

> *"Think of supply risk as a glass partly filled with water. We are OK as long as the water does not overflow. And ideally we want to be just on the limit because that's where we are most profitable. What we need to become better at managing is when and why the glass will overflow."*

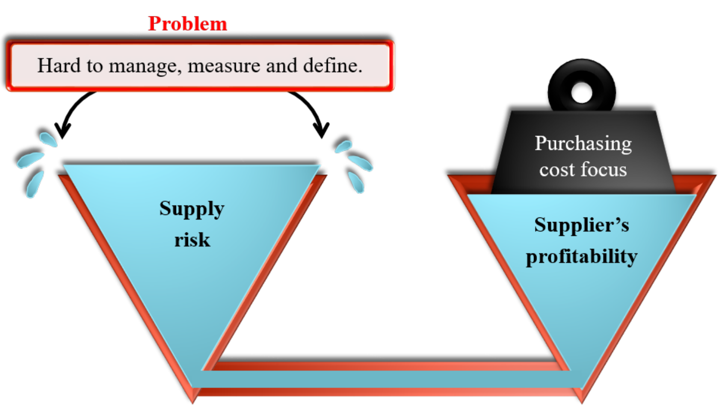


Figure 7.6: Illustration of how cost based purchasing incentives drives supply risk.

Figure 7.6 illustrates how using cost as a primary criterion when selecting suppliers increases the supply risk. This is due to the suppliers being forced to compete based on price in order to be awarded the business, and once the business is won they are prone to take higher risks in order to maximize their own profit margin. These risks are hard to define, measure and estimate with regard to potential performance impact.

Proposed improvement strategies
Cost focus is natural in all purchasing organizations, and is crucial for driving internal profits. Suggestions brought up for how to better take into account its potential negative consequences, such as increased supply risk, include:

- Developing improved routines for performing an initial supplier risk assessment
- Involving cross-functional input to greater extent in the sourcing process
- Evaluating routines for assessing *'total cost of sourcing'* instead of *'price per part'*.

7.1.1.7 Dependent on supplier competence

Problem background
One important risk area brought up by the focus group is the increased dependency on supplier competence for designing and manufacturing certain products and tools. This dependency originates either from the supplier's top tier knowledge within the field, which is hard to replace, or due to the investments made in supplier's tools or tool building competence which has made them exclusive.

Proposed improvement strategies
There exist several angles from which this issue could be approached. The first approach is to accompany the supplier in the R&D-process in order to build the internal competence needed to either do it in-house or gain the competencies required to train another supplier. However, it is difficult to convince suppliers to agree to this. The second approach is to use dual sourcing to make sure that the required competence is not exclusive to one supplier. This approach is naturally more expensive as smaller volumes will be sourced from each supplier, but it does allow for price negotiations between the suppliers and increased risk spread. A third approach, when dual sourcing is not an option, is to invest in strategic partnerships with the supplier in order to secure supply and the access to the most vital IP.

7.1.2 Supply risk areas identified within the technology industry

In addition to the seven risk areas that were either rated as most critical according to the focus group or most frequently mentioned by Aptiv managers, several supply side risk areas were emphasized by the interviewed managers from the external companies. Many of these risk areas are overlapping with the ones identified at Aptiv, however, some areas do not overlap and can thus provide complementary insights regarding the most critical risk areas faced within automotive and/or technology supply chains today.

Table 7.2: Comparison between risk areas brought up by Aptiv and the external companies

Aptiv	**External companies**	**Comment**
- Acting on preliminary order data due to mismatching supplier and customer lead time requirements. - Late design changes requested by the OEM resulting in obsolete components.	- Reduced time-to-market requirements. - Shorter product life cycles.	Shorter product life cycles is increasing the time-to-market requirements which forces OEM's to decrease development times. Hence their suppliers are pushed to act on preliminary data in order to cope with deadlines. It is also stressing the development and purchasing of new components causing design changes in late stages of the development process.
- Insufficient supplier capacity.	- Supply and material availability. - Suppliers leaving the industry.	The reason for insufficient supplier capacity seems to be due to lack of supply and material availability in combination with the increased competition for supplier between tech-industries.
- Narrow design specifications and customer designated suppliers.	Customer enforced suppliers (mentioned by one external company).	According to the frequency of which it was mentioned this risk seems to be more common within the automotive industry than in other tech-industries.
- Lack of risk related pre-information and information sharing between business units and projects.		Lack of proactive risk information and risk visualization has been emphasized by external companies. However not as a risk area, but as lack of adequate risk management processes.
- Cost based purchasing incentives.		This risk might be more significant for automotive due to inability to push costs to end consumers.
- Dependent on supplier competence.	- Sourcing from unknown suppliers.	With new suppliers and new technologies (IoT, AI, automation, etc.) gaining a larger share of the product value the dependence on suppliers with unique competencies is expected to increase.

In addition to the risk categories presented in Table 7.2 the external companies emphasized the following five risk areas:

- The risk of sourcing from unknown suppliers.
- Political tensions and trade tariffs.

- Difficulties in securing sustainability at supplier's sites.
- Cyber (and IP) security.
- Natural disasters.

These additional risks were each brought up by at least two of the six external companies. The risk areas are all concerning the automotive industry as much as the other global technology manufacturers, which is described in the remainder of this section. **The risk of sourcing from new, unknown, suppliers** was mentioned as one of the major risks by three of the six external companies. This is as well a significant risk within the automotive industry due to the introduction of new suppliers with unfamiliar technologies into their supply chains, as described by Miller (2017), Cornet et al. (2019).

The political tensions and trade tariffs were emphasized by three of the six external companies as one of the main challenges as well as by an postdoctoral researcher in logistics and sustainable supply chain management. These risks are a concern for the automotive industry as well due to the highly globalized supply chains. This is described by Campbell (2018), Reiff (2018) among many others. According to the postdoctoral researcher, political and macroeconomic events (classified as *'unknown unknowns'*) could disrupt entire supply chains without giving prior notice and is hence a major concern for global supply chains.

Difficulties in securing sustainability at suppliers sites was also mentioned by three out of six external companies and additionally emphasized as one of the main challenges by the postdoctoral researcher. This is an issue mainly for suppliers further up-stream in the supply chain. A company with hundreds of suppliers might have thousands of tier 2 suppliers and tens of thousands of tier 3 and so on. When many of these suppliers are based in low-cost countries, which often do not follow the same laws and regulations as many developed countries, sustainability issues and scandals can arise, harming the company's reputation. As for many other industries, this issue is also highly relevant in the automotive industry where a lot of raw material suppliers are based in low cost countries (Mesterharm & Tropschuh, 2012).

Cyber and IP security was brought up by three of the external companies and was also emphasized by the postdoctoral researcher. According to the whom cyber and IP security is important because in product development today, especially for high-tech components, the company boundaries are dissolving. To stay competitive in the current environment companies have to be agile and partner with market leading suppliers in collaborative networks which, to a large extent, are built on trust. To confide the company's IP with suppliers solely based on trust places the company in a vulnerable position. However, attacks and theft from outside the supply chain can also occur, resulting in disruptions and/or IP losses.

Natural disasters was mentioned by three of the external companies as one of the major risk areas for their supply chain. These events occur from time to time, sometimes causing major disruptions for the supply chain. Companies with global and geographically scattered supply chains are often particularly vulnerable to these events due to the increased likelihood that any of their suppliers or logistical transit points get disrupted.

7.1.3 Summary: Current risk areas

The risk areas identified as most important at Aptiv and the other companies differ in many aspects. However, the risk areas stressed by both categories of respondents were:

- *Reduced time to market and its implications on lead time requirements throughout the supply network.* The related effects mentioned by Aptiv were that product development processes had to be based on preliminary data which also resulted in late design changes causing obsoletes.
- *Insufficient supplier capacity.* Primarily due to supply and material availability and increased competition for suppliers between industries, where a lot of previously not tech-focused companies have started using the same suppliers.

In addition to these risk areas, the other five risk areas emphasized by the external companies are considered to be particularly important. These five areas are: (1) *Sourcing from unknown suppliers*, (2) *Political tensions and trade tariffs*, (3) *Difficulties in securing sustainability at supplier's sites*, (4) *Cyber and IP security* and (5) *Natural disasters.*

Prioritized current risk areas

Of these seven risks, five have been selected by the authors based on their comparative importance. The selection was made based on interpretation of the answers given by Aptiv, external companies and interviews with academia.

- **Supply and material availability** was emphasized by the studied auto parts manufacturer as well as by a majority of the external companies. Increased supplier landscape complexity and volatility in commodity prices is mentioned as two of the most crucial risks by Gyorey, Jochim, and Norton (2010).
- **Suppliers leaving the industry** due to increased competition for suppliers between different industries was also emphasized by the studied auto parts manufacturer and three of the external companies.
- **Reduced time-to-market requirements** is forcing companies to hasten their supply chain, causing innumerable issues. This risk area was also accentuated by the auto parts manufacturer and the external companies. Gyorey et al. (2010) describes that customer expectations has been one of the major challenges for supply chains during previous years and that getting products to market is among their top priorities.
- **Political tensions and trade barriers** was emphasized as particularly important by both external companies and academia and is hence prioritized by the authors. O'Marah (2017) and Rice and Zegart (2018) is describing geopolitical issues as one of the major concerns for supply chain managers.
- **Securing sustainability at supplier's sites** was also emphasized by both external companies and academia. Berns et al. (2009) describes that leading companies are pushing suppliers to improve their sustainability and that sustainability is often the deciding indicator when selecting new suppliers.

7.2 Future supply risk areas

This section consists of an analysis of which supply risk areas are expected to become most critical for the automotive and technology industry in the near future. First, the supply risk areas that Aptiv are currently facing are analyzed in terms of their future development. In the second part the expected future risks identified through interviews with the external companies are described. Lastly, a summary of the most critical future supply risks is presented.

7.2.1 Future supply risk areas identified at Aptiv

The automotive industry is currently undergoing a significant transition that is expected to influence what risk areas will be most significant in the coming years. The major trends described in chapter 4.6 describes that the introduction of shared mobility, autonomous vehicles, electrification and connectivity may change the power balance between, and the core competences of, OEMs and their suppliers. In addition to this the requirements on emission levels, development time, time-to-market and cost reductions are increasing, further challenging the industry.

The future outlook for the seven most critical risk areas brought up by the auto parts manufacturer is described below and is illustrated in Figure 7.7. The future outlook for each risk area is analyzed in terms of how the trends described in chapter 4.6 will affect the future importance of the risk area.

- The risk of *'Acting on preliminary order data due to mismatching supplier and customer lead time requirements'* is expected to grow during the coming years. This issue is rooted in short time-to-market requirements which are expected to increase even further during the forthcoming years and hence this risk is also expected to increase.

- *'Late design changes requested by the OEM resulting in obsolete components'* is partly also an effect of short time-to-market requirements. This increase is primarily due to the rapid introduction of new automotive technologies and the fact that several OEMs have announced plans for shortened development times, such as Volvo committing to 20 months time-to-market by 2020 (Schwartz, 2015; Andren, 2015). Moreover, high paced technical development may also result in a greater need for late design changes in order to keep the products up-to-date.

- *'Insufficient supplier capacity'* is an ongoing issue existing mainly due to two reasons. The first reason being the increased amount of car sales in recent years (Scotiabank, 2018). According to Gao et al. (2016) car sales is expected to continue to increase, however Scotiabank (2018) is expecting the car sales to stop growing. The second reason is the increased demand for high-tech suppliers in many industries due to investments in modern technologies such as IoT and AI. The competition of technology suppliers between industries is expected to grow and hence the supply shortage is expected to continue.

- Indicators implying that the risk of *'Narrow design specifications and customer designated suppliers'* will increase are scarce. However, as the technological complexity of the vehicles continuous to grow, the OEMs will want to continue using systems and suppliers of which they have experience from and hence the occurrence of customer designated suppliers may increase. Yet, no conclusions can be drawn based on these speculations.

- *'Lack of risk related pre-information and information sharing between business units and projects'* and *'Cost based purchasing incentives'* are expected to diminish as the systems and tools for risk management and total cost of ownership analysis grows more powerful with the help of new technologies, such as BI, AI and big data.
- The risk of becoming *'Dependent on suppliers competence'* is expected to increase as the products become more technically advanced. The OEMs will become particularly vulnerable to this risk if they do not transform their business models or develop their core competences (Cornet et al., 2019).

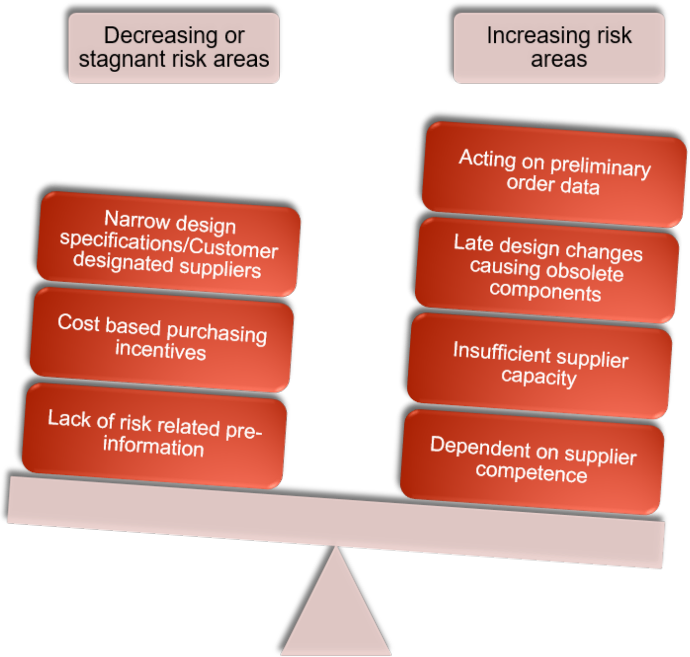


Figure 7.7: Future development of the risk areas identified during the case study.

7.2.2 Future supply risk areas within the technology industry

Through interviews with the managers from the six external companies, risk areas that are expected to grow in significance were derived. The answers are based on the trends that the interviewees' industry is currently experiencing and other societal trends believed to inhibit their supply chain. The risk areas expected to increase, stated by at least two of the six external companies are listed below:

- The risk related to *'Supply and material availability'* is expected to grow due to a resource scarcity regarding many non-renewable materials. The supplier availability is also expected to decrease mostly due to increased competition of suppliers across industries.

- *'Suppliers leaving the industry'* is one major reason for supply shortage and occurs due to increased competition for suppliers across industries.
- *'Political tensions & trade barriers'* are expected to increase according to the external companies. The main reason being the increased tension between the global superpowers.
- *'Reduced time-to-market requirements'* are expected to increase due to the fast-paced consumer market and technological development forcing companies to reduce development times in order to stay up-to-date.
- *'Cyber and IP security'* increases in importance due to digitization, open source development and increased reliance on supplier networks.
- The risk with *'Sourcing from unknown suppliers'* will increase due to the rapid introduction of new technologies.
- The trend towards *'Shorter product life cycles'* exists due to changing customer demands and intensive technological development. This is increasing the requirements on reduced time-to-market.
- Multiple respondents are expecting risks associated with *'Natural disasters'* to increase due to climate changes. The occurrence of typhoons, floods and dry periods will increase in the future, which can potentially disrupt any supply chain.
- *'Difficult to secure sustainability at supplier's sites'* is expected to increase due to globalization of supplier networks, even though there exist cases of re-shoring initiatives (Moradlou, Backhouse, & Ranganathan, 2017). Moreover, shifting low cost countries is also making it more difficult to control tier n suppliers.

7.2.3 Summary: Future risk areas

Most of the risk areas expected to increase within the case company's supply chain are overlapping with those identified via the external companies, as presented in Table 7.2. These risk areas are: (1) Reduced time to market and its implications on lead time requirements throughout the supply network; (2) Insufficient supplier capacity due to lack of supplier and material availability; and (3) Sourcing from unknown supplier due to new technologies and suppliers entering the market and existing suppliers leaving the industry.

In addition to these risk areas emphasized by both Aptiv and the external companies, the external companies are also predicting an increased importance of the following risk areas:

- *Political tensions & trade barriers.*
- *Cyber and IP security.*
- *Natural disasters.*
- *Difficulties securing sustainability at supplier's sites.*
- *Suppliers leaving the industry* - a reason for both insufficient supplier capacity and the need to source from unknown suppliers.

Prioritized future risk areas

Of these eight risk areas, four have been selected by the authors as particularly important. The selection is based on the authors interpretation of the answers given by Aptiv, external companies and interviews with academia.

- **Supply and material availability**, with emphasis on material availability, is considered one of the most crucial risk in the future. This was emphasized by the case company as well as by three of the external companies. Resource scarcity is a present problem affecting companies supply chains and is a continuously increasing risk (Mancini, De Camillis, & Pennington, 2013).
- Issues related to **Reduced time-to-market requirements** is expected to increase due to increased market demands and technical complexity. This was stressed as a future risk area by both Aptiv and the external companies. Getting products to market faster was also one of the future top priorities for the respondents in Gyorey et al.'s (2010) research.
- **Political tensions and trade barriers** is expected to increase by all external companies experiencing this risk, as well by academia. This risk area is expected to see some growth in the near future (O'Marah, 2017) and most companies do not consider themselves prepared to handle this type of challenges (Gyorey et al., 2010).
- **Cyber and IP security** was also emphasized as particularly important to consider in the future, by both external companies and academia. Deutscher (2017) stresses that this risk should be a prioritized area for all large companies, and many companies are already experiencing an increasing concern regarding how this risk can be handled in the future (AON, 2019; O'Marah, 2017).

7.3 Risk factors for assessing supply side risk

This section aim to answer RQ3 by presenting a set of risk factors for assessing supply side risk as part of a four-step risk assessment framework. The proposed framework consist of four sequential assessments, starting with an analysis of the company's *internal risk appetite* for assessing what level of risk is accepted. Followed by a *product risk assessment* for determining what risks are associated with a specific component/product. Thirdly, assessing *supplier risk* for determining the risks associated with specific suppliers. Lastly, step four being a regional risk assessment where indicators attributed to the region in which the supplier operates are to be assessed.

The risk factors were derived partly from assessment procedures used today by the case company, and partly selected by the authors from the list of risk factors presented in section 4.5. An overview of the four-step framework is presented in Figure 7.8 and its associated risk factors is presented in Figure 7.9.

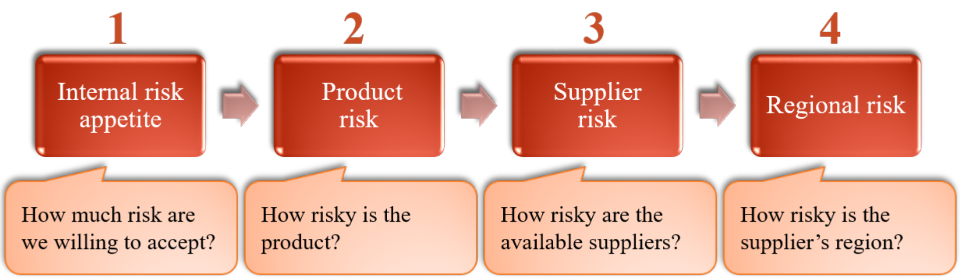


Figure 7.8: Proposed risk assessment framework overview.

A description of the framework and the purpose of each assessment step is presented below:

Step 1: Internal risk appetite assessment

The purpose of this phase is to determine the amount of risk that is accepted by the company. A high degree of risk taking can lead to increased profits, but at the same time the company will be more prone to be affected by any disruption, such as the case of using single- instead of multi-sourcing. Normally risk appetite is a strategic decision determined by upper management for the entire company, and is something that applies for all product series. However, it can also be determined on a product/component basis where strategically important products are assigned a low risk appetite, and for commodity type products a higher risk appetite may be deployed.

By determining the internal risk appetite, thresholds for what amount of risk is allowed in the remaining phases can be assigned. For example, assume that the *product risk* assessment phase has a maximum risk score of 50, where 50 is the maximum risk and 0 the minimum. If a high risk appetite is assigned, the threshold for what is considered acceptable in the *product risk* assessment phase can be set to <35. Whereas if a low risk appetite is assigned, a lower threshold set to <15 can be deployed. Consequentially, all the remaining phases and what amount of risk is allowed depends entirely on the initial risk appetite assessment.

Step 2: Product risk assessment

Once an internal risk appetite is determined, phase two aims to assess the amount of risk associated with manufacturing and selling a specific product. Factors under consideration include how critical the product is in order to retain existing customers and win new businesses, the supply availability and whether the required competencies match the company's core competencies. Additional risk factors are presented in Figure 7.9. The purpose of the phase is to evaluate whether the associated benefits of committing to produce and sell a specific product outweighs the potential risks.

Step 3: Supplier risk assessment

When the product risk assessment has been conducted and a decision has been made to commit to full-scale production, the next phase aims to assess specific supplier risks. This includes risk factors such as supplier specific competencies, manufacturing flexibility, capacity utilization and ramp-up planning, customer portfolio, cyber security systems, amongst others.

Step 4: Regional risk assessment

Lastly, once supplier specific risks have been evaluated, a regional risk assessment is to be performed. The indicators under evaluation are those attributed to the region in which the supplier operates, but not necessarily factors of which the supplier has any influence. Such factors include regulatory and legal changes, political stability, infrastructure reliability and the region's tendency to be affected by natural disasters.

Proposed risk factors

The proposed risk factors to evaluate in each of the four phases are presented in Figure 7.9.

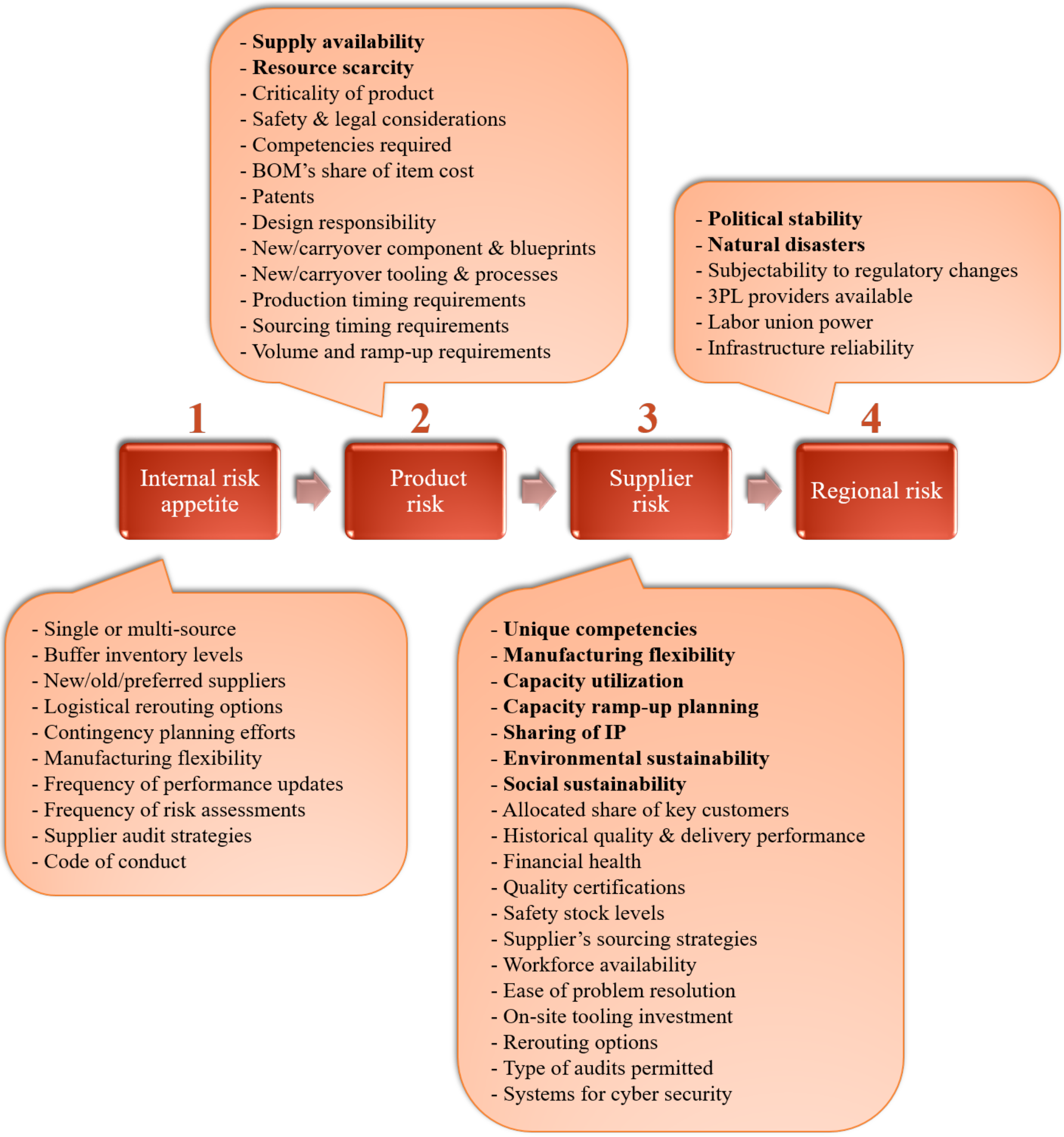


Figure 7.9: Risk factors included in the proposed risk assessment framework.

Risk factors considered particularly important to cope with the primary risk areas that are expected to increase in the future are highlighted in Figure 7.9 with bold text. These are not factors that are missing in the risk assessment procedures used by the interviewed companies today, but are rather factors that would benefit from receiving increased focus in order to cope with the changing supply side and business environment. How and why these selected risk factors are particularly important, and how they can be utilized, is described in more depth in Table 7.3.

Table 7.3: Proposed risk factors requiring additional focus to cope with the emerging risk areas.

Risk factor	**Related risk/-s**	**Purpose**	**Proposed risk weight assessment** (High value = high risk)
Supply availability	- Suppliers leaving the industry. - Insufficient supplier capacity. - Resource scarcity.	Aims to assert whether supply availability is going to be a potential issue.	1: More than five supply options, suppliers are ramping up production and resource access is abundant. 3: Three or more supply options, supplier capacity is stagnant, resource access is stable. 5: Less than three supply options, supplier capacity is stagnant or decreasing, resources are scarce.
Sharing of IP	- Cyber security. - Market share loss. - Copied products/ processes.	Aims to assert that IP will not fall into the wrong hands (i.e. direct competition).	1: Supplier has up-to-date IT security systems, does not supply to any direct competition and has invested in preventive IP leakage measures. 3: Supplier supplies similar products to competitors and has limited IP safeguard functions. 5: Supplier supplies to multiple direct competitors and has no systems for safeguarding against IP theft.
Capacity utilization and ramp-up planning	- Insufficient supplier capacity.	Aims to assert the supplier's current ability to produce/supply the required quantities.	1: Workforce, tooling and equipment in place. Run-at-rate and PPAP approval is readily available. 3: Minor ramp-up is required, including workforce hiring and setting up new tooling. 5: Major ramp-up and expansion required.
Manufacturing flexibility	- Late design changes. - Sourcing based on preliminary data.	Aims to evaluate how flexible the supplier is for adapting to design changes.	1: Short lead times, high level of standardization, design postponement and agreement to use composite drawings. 3: Average lead times and product standardization. 5: Unique designs with low level of standardization, long lead times and extensive verification process required.

Unique competencies	- Dependence on supplier competence. - Buyer/seller power balance.	Aims to assess how much dependency is placed on the supplier.	1: No on-site investments, multiple supply sources available, no patent restrictions. 3: Average on-site investments, limited supply sources available. 5: Significant on-site investments, single source of supply, patents prevent in-house production.
Supplier sustainability	- Sustainability at supplier's sites.	Aims to assess the supplier's ability to comply with the required social and environmental sustainability regulations.	1: Certified and previously known supplier. Little to no sustainability issues has occurred in previous collaborations. 3: To some extent certified and previously known supplier with only minor previous sustainability issues. 5: Unknown supplier missing important certifications or known suppliers with major sustainability issues.
Political stability	- Political tension & trade barriers.	Aims to evaluate the political situation in the region of the supplier and its estimated implications for the sourcing activities.	1: Politically stable region with low exposure to sanctions and other trade regulations. 3: Politically uncertain regions currently exposed to minor trade regulations. 5: Region in political turbulence and/or exposed to major trade regulations.
Natural disasters	- Disruptions caused by natural disasters.	Aims to evaluate the regions exposure and vulnerability to natural disasters.	1: Little to no occurrence of disruptions due to natural phenomenons. 3: To some extent exposed to natural phenomenon disruptions, sometimes causing delays and supply shortages. 5: Heavy exposure to natural phenomenons causing annual disruptions.

7.4 Proactive supply risk management

This section aims to answer RQ4 by first presenting emerging tools and technologies for proactive supply side risk management that were identified through interviews with the external companies. Section 7.4.2 then uses these technologies, combined with additional theoretical and empirical evidence, to analyze what strategies are appropriate for managing supply risk more proactively. Lastly, in section 7.4.3, three proof-of-concept supply risk dashboards developed by the authors are presented. The intended purpose of the dashboards is to assist with visualizing and communicating risk related information in an efficient way, and to showcase how supply risks may be managed differently in the future.

7.4.1 Emerging risk management tools and technologies

Five emerging tools for improved supply chain risk management were identified through the external interviews. These tools, their primary function and their respective purpose is summarized in the remainder of this section.

Geo-analytics platform for anomaly detection

One risk identification system currently in use at the networking and telecommunication manufacturer is utilizing real time data from online map services in order to detect anomalies such as force majeure, conflicts, major accidents etc. Hence, this system assists in proactively mitigating the risks related to natural disasters, which was brought up as an increasing risk by multiple respondents.

The functionality of the system was described by the respondent as when an anomaly occurs in close proximity to any of their supply nodes (tier n suppliers, warehouses, etc.), contact is initiated in order to secure that the anomaly will not disrupt the supply from the concerned node. However, if a disruption is deemed likely, preventive measures or alternative supply sources can be established proactively. This system can be described as a more intelligent and automated version of a similar geographic information system presented by The European Commission in 2008 (Peggion, Bernardini, & Masera, 2008).

AI analyzing social networks and news feeds

The networking and telecommunication manufacturer were also currently developing a system using AI to scan social media and news feeds in order to detect potential supply risks. The scope of supply risks covered in this system is wider than for the disaster management system and will, over time, be able to identify early risk indicators for events such as upcoming labor strikes, political turmoil, accidents, new regulations and force majeure. This system can help detect and proactively handle political tensions, trade barriers and even help identify natural disasters at an early stage. Moreover, as the data set on which the AI is set to train grows bigger, the forecasting accuracy is expected to increase.

The intended functionality of this kind of system is based on mapping key words and sentences and identifying patterns in the data (Twombly, 2018). The system will be able to cross-reference past events to corresponding news and social media feeds. By examining previous activities, future events that may potentially harm the supply chain can be predicted (Hajibashi, 2018).

Source code management system

The electrical equipment manufacturer were using open source development for many of their systems and products. In order to control the risks associated with open source development, they used a source code management system called from Black Duck Software (Synopsys, n.d.). Their newly implemented system enables them to scan source code for its origins and licenses and it helps them to approve the code according to given policies and regulations. Incorporating open source projects into commercial projects brings with it many challenges as you rely on independent parties for updates and bugfixes. By utilizing an open source management system, these kind of risks can be managed more effectively.

IP protection by using blockchain technology

It is often difficult to detect IP or copyright thefts, and when thefts are detected it is often challenging and costly to prove that a crime has been committed, which is necessary in order to receive indemnity. However, the advent of blockchain technology will help companies create digital trails of records of innovation processes to enable secure handling and tracking of IP. The blockchain certificates enable proof of existence and ownership and information could be kept private. It will also enable safer IP registry services by eliminating the third-party (Clark & McKenzie, 2018). This technology will help companies protect themselves from IP thefts and cyber attacks which was identified as an increasingly important risk area.

Sub-tier whistleblower system analyzed by AI

Digital diaries for sub-tier suppliers can be used to secure that rules and regulations are obeyed. This is particularly useful for identifying deficiencies regarding both social and environmental sustainability, but can also be used in order to forestall quality issues. By introducing a whistleblower system where any employee on a daily basis can report incidents or regulatory noncompliance, these issues can be handled before they reach the public. By having the digital diaries analyzed by AI trained to search for key words and phrases, abnormalities can be identified in an early stage. If many issues are reported within the same area, actions can be taken to prevent the issues from spreading. Examples of issues include excessive working hours, bribery, employee safety failings, discrimination or quality controls deviating from the agreed upon standards. This system may assist companies in securing sustainability at lower tier supplier sites without having to perform regular audits.

7.4.2 Key strategies

This section is comprised of an interpretive approach with multiple inputs and outputs where the authors make use of the findings required for answering RQ1-3 as a foundation for answering RQ4: *What are key strategies for proactive supply risk management in the future?*

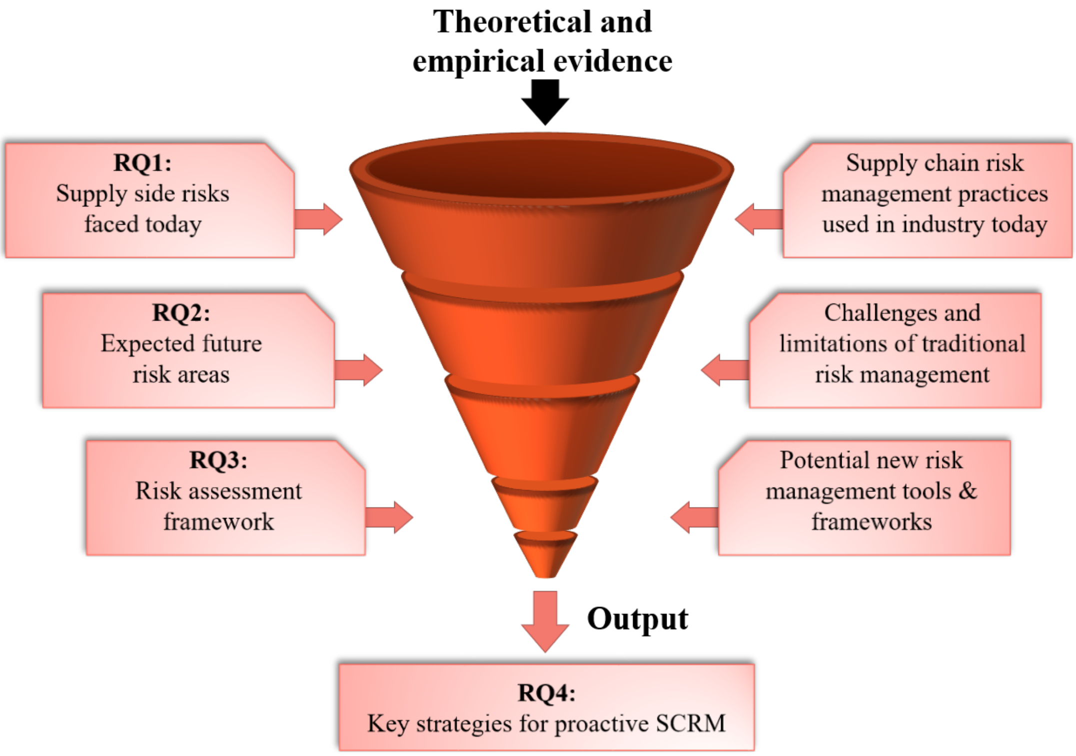


Figure 7.10: Overview of the empirical and theoretical findings used to answer RQ4.

Working proactively with supply chain risk management was identified as highly sought for by industry experts, but difficult to implement in practice. More so due to the fact that the supply side risks of today will not be the same as the risks of tomorrow. The studied literature strengthens this claim, both via independent researchers and from the increased number of management consultancy reports touching on the topic.

Based on the theoretical and empirical evidence retrieved, the authors have narrowed down three strategies for becoming better at proactive supply risk management in the future. The proposed strategies are: (1) Supplier development and strategic partnerships; (2) Early risk indicator analysis and governance; and (3) Transitioning to more technically advanced decision support systems for managing supply risk. The remainder of this section outlines and discusses the respective strategies in more depth.

Supplier development and strategic partnerships

Working proactively with supply risk requires a high level of supply chain visibility, access to risk related information and insight into potential risk areas that may impact upstream suppliers. One approach for doing so is by investing in strategic relationships with suppliers.

Naturally, it is unrealistic to initiate strategic partnerships with all suppliers and companies tend to do it only for a selected few of particular strategic importance. However, the increased occurrence of so called *innovation hubs* is a testimony to that investing partially in supplier development, albeit not a full-blown strategic partnership, is increasingly becoming a valid and financially justifiable option. Not only does initiatives like innovation hubs provide platforms for knowledge sharing, but also enables a greater risk transparency.

Moreover, the more effort and investments that are put into supplier development (such as through on-site tooling investments, on-site training, IP sharing, etc.), the better insight you will have into the risks faced by your upstream suppliers.

Early risk indicator analysis and governance

A key component of being able to work proactively with supply risk is having access to early risk indicators. This requires continuous access to risk information that is not only impacting your own company's operations, but also risks impacting your upstream suppliers. The traditional approach for retrieving information about sub-tier suppliers is to simply ask the tier-1 suppliers. Based on a CSCO survey from 2014 where 942 companies were interviewed, two-thirds of companies said they do it this way (Geraint, 2014). Whereas half of them claimed they rely on internal or third-party intelligence.

As presented in section 4.7, these traditional approaches tend to result in a very limited supply chain transparency. Only 35% of respondents from the aforementioned CSCO survey were confident about their insight into their tier-2 suppliers, further decreasing to only 17% for tier-3 and beyond suppliers.

This limited transparency is an effect of suppliers being generally reluctant and unwilling to disclose details about their own suppliers. Primarily due to competitive reasons such as the risk of leaking information that may prove beneficial for their direct competition. The importance of supply chain visibility as a decision making criteria when selecting suppliers is emphasized by multiple researchers (Nooraie & Mellat Parast, 2015; Tse & Tan, 2012). Although supply chain transparency itself does not minimize risk, it is the foundation on which effective proactive risk management can be built.

Transitioning to more technically advanced decision support systems for managing supply risk

An important part of the transition towards a proactive supply risk management approach is to take advantage of, and implement, more technically advanced decision support tools. The requirements for new tools and techniques for risk management decision making is emphasized by consulting firms (Capgemini Consulting, 2017; McKinsey & Company, 2016), SCM organizations (Geraint, 2014) and the managers interviewed during this study.

New technologies such as, BI, AI, big data, geographic & social media analytics and blockchain will help supply chain managers predict occurrence of potential high-impact disruptions at an earlier stage and assist in proactively mitigating their impact. With improved predictions of potential supply chain disruptions, mitigating measures for events with high-impact, low-probability could be taken when required in order to increase the supply chain resilience. As described in section 7.4.1, using new technologies can facilitate the management of geopolitical risks, natural disasters, IP protection and sustainability issues in the supply chain, of which many could be classified as high-impact, low-probability events. However, this is merely a small selection of all potential supply risk management applications for these new technologies.

Implementing new tools and technologies for risk management will require significant investments, and even though many executives are aware of the importance of risk management activities it is only the seventh most frequently prioritized area by upper management (Gyorey et al., 2010). The business dilemma regarding risk management investment is how to prove its return on investment (ROI). The risk management investments need to be balanced against the costs that the company has managed to avoid (Berg, Knudsen, & Norrman, 2008). How to measure these savings in order to prove ROI calls for additional research.

7.4.3 Proposed supply risk dashboards

A set of three dashboard concepts were developed by the authors as a practical complement to the study's theoretical findings. The proposed concepts aim to showcase how supply chain risk can be visualized, communicated and aggregated. Furthermore, the dashboard concepts showcase how early indicators of risks and anomalies in the supply chain can facilitate proactive risk mitigation actions to be put in place. Each of the three proposed dashboards are explained throughout the remainder of this section, including a set of potential use cases.

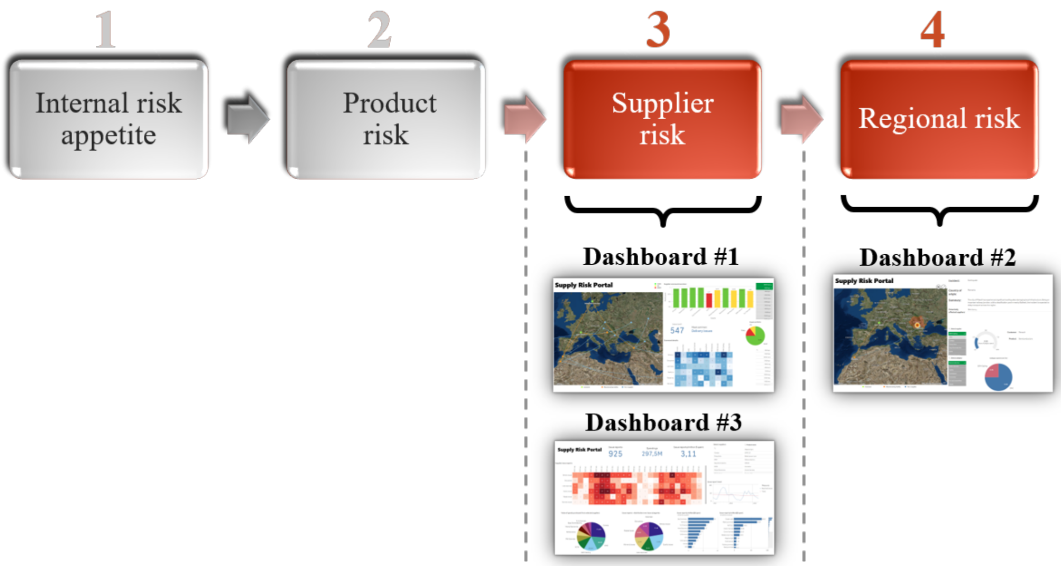


Figure 7.11: Overview of the proposed dashboards' focus areas.

The dashboard concepts are connected to the risk assessment framework presented in section 7.3. Where dashboard 1 and 3 aims to assist in evaluating *supplier risk*, whereas dashboard 2 aims to showcase how *regional risk* can be managed using geo-analytics.

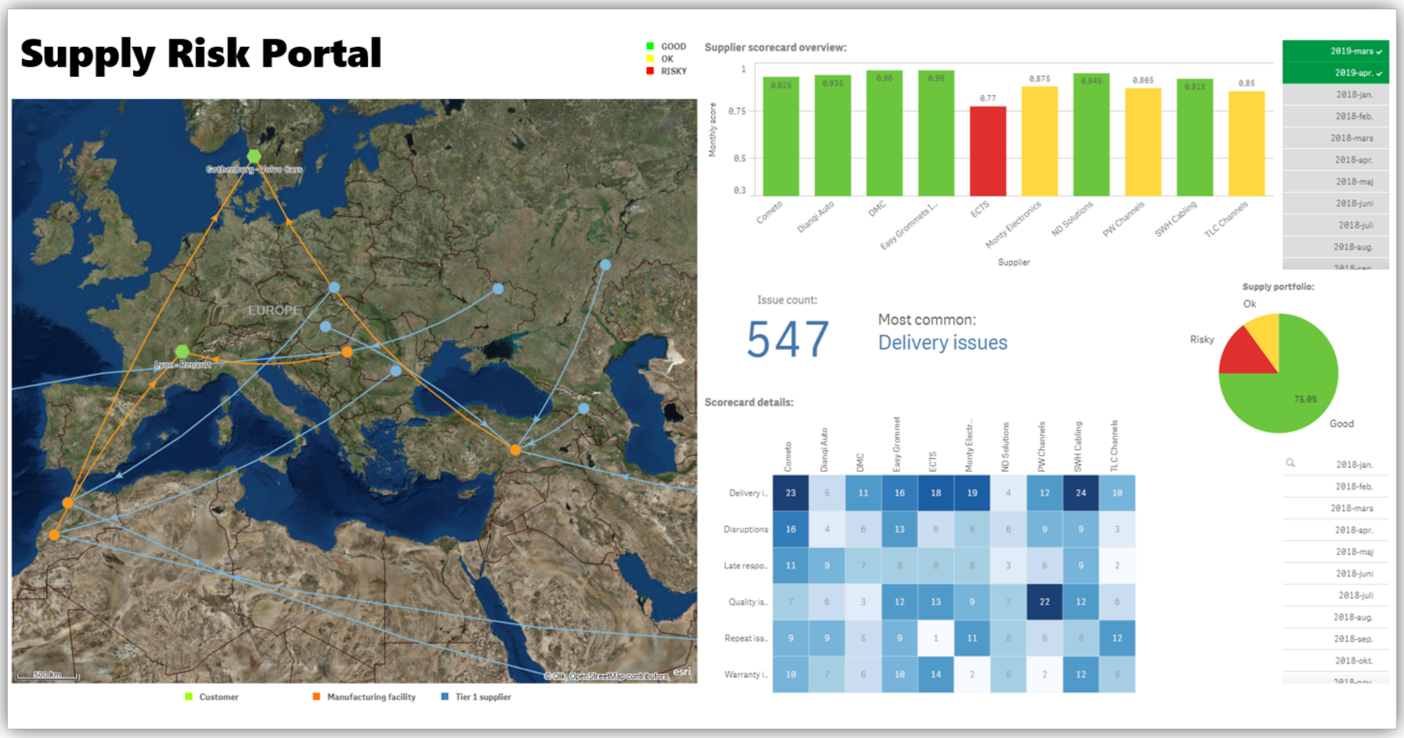


Figure 7.12: Dashboard concept 1: Supplier risk overview.

Dashboard 1's purpose is to: (1) provide a geographic overview of the supply chain; (2) provide the user with supplier scorecard metrics; and (3) to provide details regarding issued problem cases at different suppliers over a selected period of time. The intended usage is to visualize the supply chain flows and to provide a high-level overview of supplier performance to a mixed/cross-functional audience. Two examples of potential use cases are presented below.

Use case 1:
Background: Cross-functional meeting with Purchasing, Engineering and Supply chain departments.
Goal: Purchasing is considering changing supplier X, but wants to get additional input from engineering and supply chain before they make a decision.
Usage: Purchasing managers use the dashboard to motivate their proposed change of supply source, where the attendees are invited to lift their opinions.

Use case 2:
Background: Upper management supply portfolio performance overview.
Goal: Getting a high-level overview of supplier performance and risk.
Usage: Using the dashboard as a presentation tool for bringing the attendees up-to-speed with current supply portfolio performance and risk status.

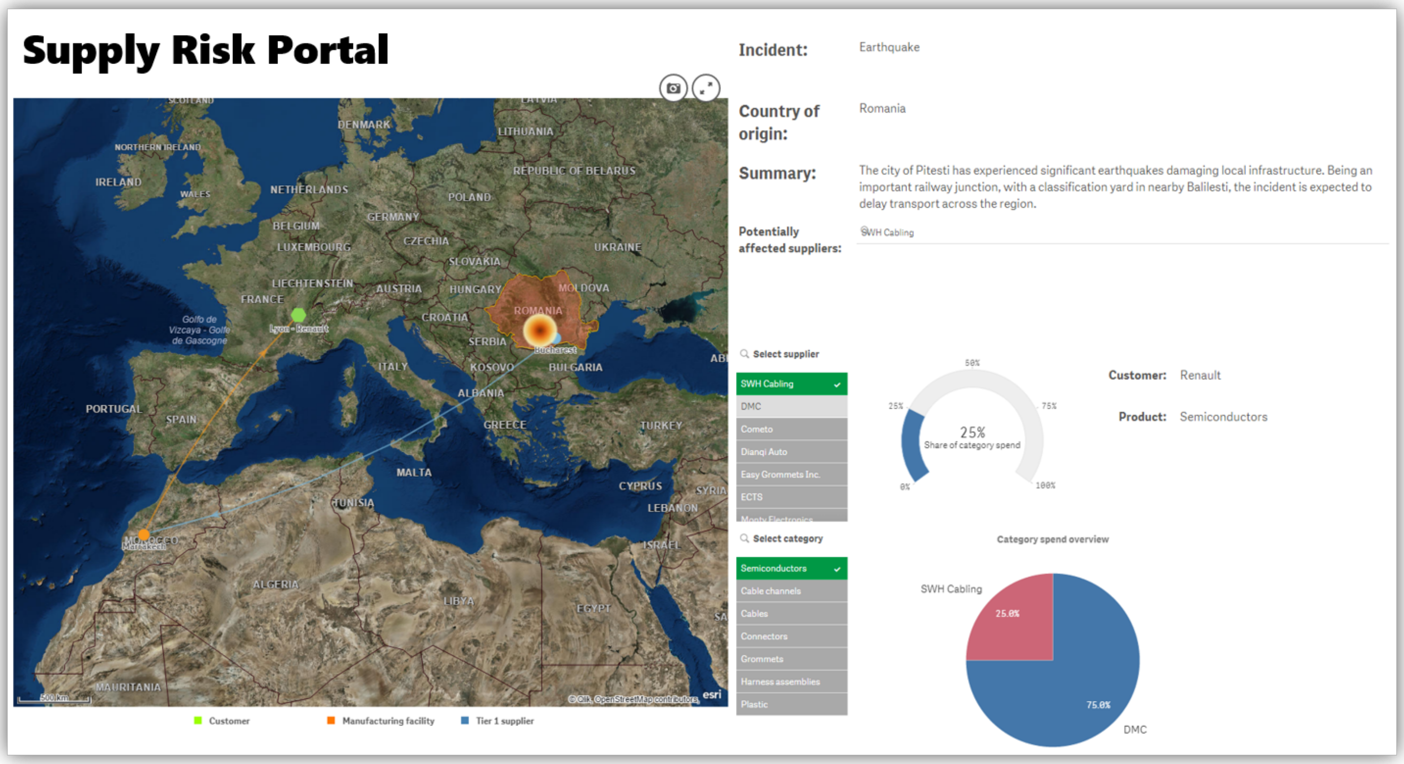


Figure 7.13: Dashboard concept 2: Geo-analytics.

Dashboard 2's purpose is to visualize regional risk using geo-analytics and how various disruptive events may impact the supply chain. This is done by highlighting countries and regions in which a disruptive event has been registered, and by presenting a brief incident description, country of origin and potentially affected suppliers. The user can then select any supplier and get an overview of (1) how large share of the product category is being sourced from the affected supplier and (2) how many alternative suppliers are currently supplying the same product.

The incident data presented in the dashboard is fictitious and is retrieved from locally stored files. However, the data is intended to be fetched remotely from either third party companies supplying risk data, freely available sources such as Google maps, or from an external web API.

Use case 1:
Background: An incident has been registered in a region close to a tier-1 supplier.
Goal: Act quickly based on the available risk information.
Usage: Initiate contact with the supplier as soon as the incident has been registered. Assess the likelihood of being affected by the event and set up early contingency plans, alternative supply sources or rerouting options.

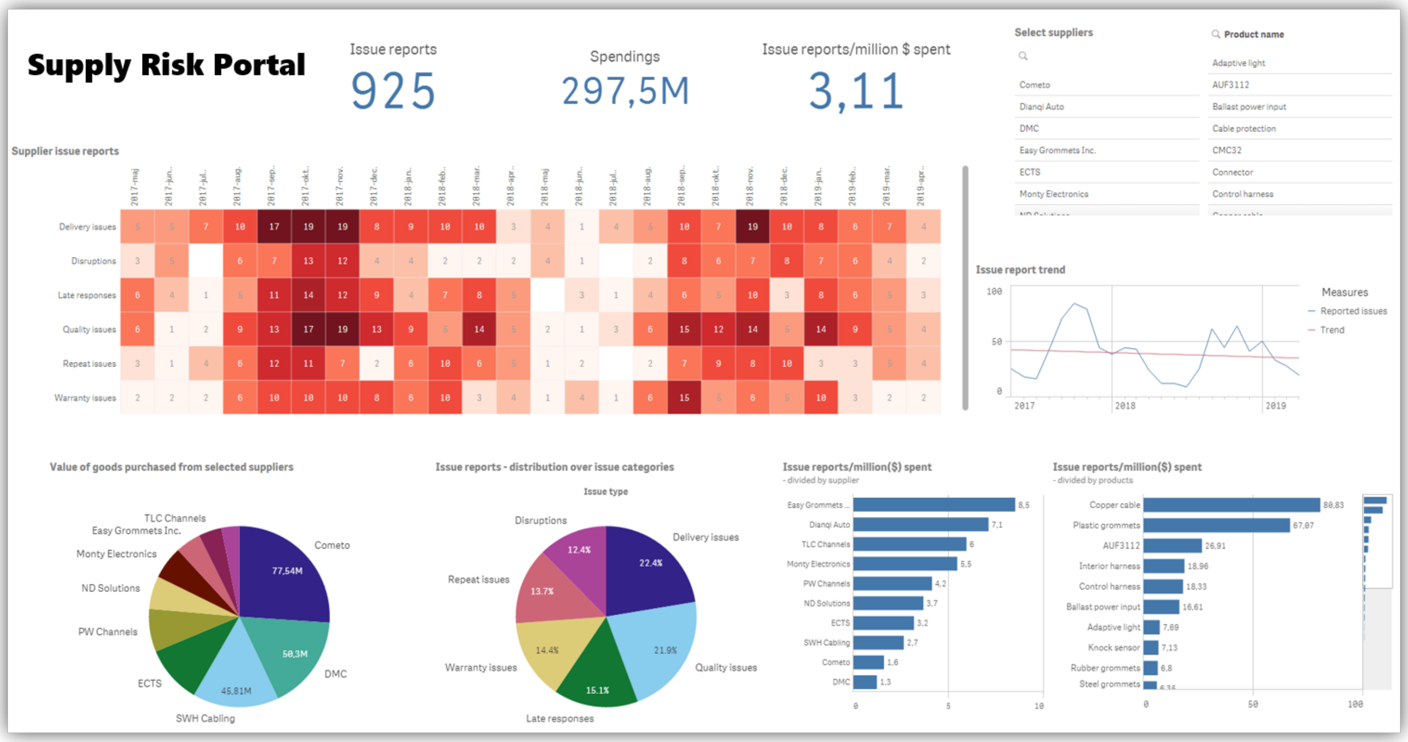


Figure 7.14: Dashboard concept 3: Issue report handling.

Dashboard 3's purpose is to: (1) display when and why issues occur in the sourcing process; (2) provide information regarding which suppliers and products cause the most issues; and (3) to display the frequency of different categories of issues. The dashboard aims to visualize supply chain issues and to provide an overview of which parts of the supply chain risk mitigation resources should be focused on. Two examples of potential usage scenarios are presented below.

Use case 1:
Background: The number of issue reports are increasing.
Goal: Identify and mitigate the root cause for this increase.
Usage: Identify which product groups, suppliers and/or issue types are causing the increased number of issue reports. Further, identify the reason for these issues occurrence from the corresponding reports and take appropriate actions.

Use case 2:
Background: Gathering of information during a supplier selection process.
Goal: Perform a proactive supplier risk assessment of a previously known supplier before entering the contractual stage.
Usage: Assess the supplier's previous performance to identify the major risk areas. By identifying the major issues, risks could be handled proactively by either contractual arrangements or other risk mitigation strategies.

8

Conclusion

This chapter summarizes the main research findings and provides brief answers to each research question. Moreover, it outlines the primary recommendations for the case company and suggests potential future research areas.

8.1 Research findings

The primary research findings are outlined in this section by providing answers to each of the four research questions.

(1) Which are the most critical risk areas experienced in technology supply chains today?

Throughout the empirical research several supply side risk areas were emphasized by multiple respondents and further solidified by the studied literature. These include: (1) Suppliers shifting industries in an attempt to increase profits as more and more industries are requiring the same suppliers; (2) Supply capacity is limited as the demand for the same components increases; (3) Political tension and uncertainty is increasing, with the introduction of new regulations, environmental standards and trade barriers; (4) Reduced Time-To-Market requirements are increasingly challenging for development and sourcing lead times; and (5) Difficulties assuring suppliers' on-site sustainability.

(2) Based on trends and the future outlook of the technology industry, which risk areas are most likely to be important in the future?

The global and industry specific trends are continuously changing the environment in which companies operate. The current trends in the supply risk landscape will require companies to adjust their supply risk management focus. In the near future additional focus and resources has to be placed on: (1) Securing access to scarce resources and designing products based on the available material; (2) Monitoring geopolitical tension and the introduction of new legislative actions; (3) Adapting to reduced Time-To-Market requirements by speeding up sourcing and development times; and (4) Safeguarding against IP theft with increased focus on cyber security.

(3) What risk indicators can be used to assess supply side risks?

The authors have developed a risk assessment framework consisting of four distinct steps. Firstly, indicators for determining an *internal risk appetite* are provided. This step aims to determine how much risk the company is willing to take. Secondly, factors for assessing the overall *product risk* are proposed. This step aims to assess how risky it is to commit to producing a specific product. Thirdly, indicators for evaluating *supplier risk* are proposed. These aim to assess the risk exposure that selecting a specific supplier will bring. Lastly, factors for assessing *regional risk* are proposed. The purpose being to evaluate the risks associated with the region in which the selected supplier operates.

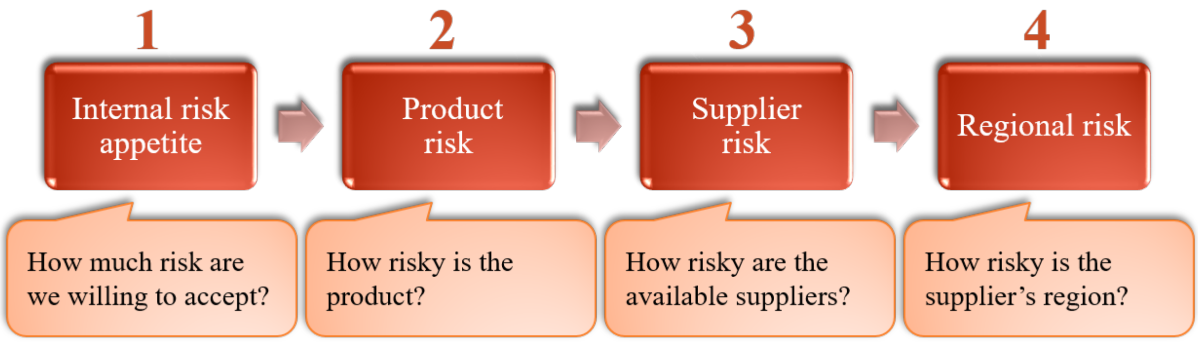


Figure 8.1: Summary of the proposed risk assessment framework.

The proposed framework was derived partly based on internal procedures used by the case company, combined with insights drawn from studied literature and external interviewees.

(4) What are key enablers for proactive supply risk management in the future?

Several strategies for improved proactive risk management have been identified. The three primary strategies requiring additional focus are:

- **Supplier development and strategic partnerships.**
  Risk sharing through cross-company collaborative initiatives is not only gaining ground via the introduction of more and more innovation hubs, but strategic partnerships is becoming increasingly common as the technical complexity of products increases.

- **Early risk indicator analysis and governance.**
  Companies today gather vast amounts of performance related data from their suppliers but early risk indicators are more scarce. Additional focus needs to be put on continuously monitoring risks by either (1) setting up systems for identifying and evaluating risks using available data online or (2) by enforcing stricter supply chain visibility requirements on sub-tier suppliers.

- **Transitioning to more technically advanced decision support systems for managing supply risk.**
  Traditional risk assessments using manual analysis of a set of predetermined factors is highly suboptimal. The introduction of AI and big data analytics allows for systems to be developed that continuously monitor risk factors and can provide early warning signals, which when combined with managerial input, can assist in making well-informed business decisions.

8.2 Recommendations for improved risk management capabilities

The author's recommendations on how to improve current supply chain risk management capabilities for companies exposed to supply risks are divided into two time horizons: *short-term* and *long-term* commitments. These recommendations, their purpose and what motivates them is outlined below.

Short-term suggestions
The mutable environment of risks impacting technology companies calls for a revision of current KPIs and risk factors in order to cope with the prevailing risk environment. This revision could include, but is not limited to, the risk factors included in the proposed risk assessment framework (Figure 7.9), some of which are explained in more depth in Table 7.3.

During the study the authors identified a need for better supply chain risk visualization, communication and aggregation within several companies. By replacing or complementing some of the current spreadsheets with pedagogic visualization tools, risks and issues could not only be identified and mitigated at an earlier stage, but it could also enable other functions and units of the companies to understand risks and contribute to the choice of mitigation strategies. Examples of such visualization tools are the dashboards introduced in section 7.4.3.

Long-term suggestions
From a long-term perspective, companies like Aptiv that are continuously faced with uncountable numbers of risks and who are operating in a volatile industry, would benefit from implementing analytic tools that enable continuous and automated monitoring of risk factors. This is in direct contrast to current supply risk assessments which are primarily based on a snapshot of current states and might fail to perceive swift alterations in supplier performance and introduction of unknown risks. Hence, to provide early warning signals, which will assist in proactive risk management, continuous updates of supplier KPIs and risk factors has to be implemented. This can be done by integrating either of the new technologies presented in this report into the risk management systems used today. However, this development and integration would require corporate engagement and substantial monetary investments.

A static risk management approach will not serve as an efficient method to anticipate and forestall prevailing and forthcoming risks in long-term. In order to succeed with this, a proactive risk management approach with integrated routines for evaluation and readjustments is required. As identified in this study, supply chain risks are not static but rather a dynamic and constantly impeding threat requiring continuous improvements and knowledge updates to be managed efficiently. Thus, the current risk management approach calls for an implementation of routines that continuously and dynamically update which risks are assessed and monitored.

8.3 Future research

Due to the high level nature of this study, several areas requiring additional research have been derived. Firstly, additional research regarding the availability of supply side risk data is required. Companies today gather vast amount of performance data from suppliers, partly provided by the suppliers themselves and partly derived by the purchasing company.

Risk related data however is more scarce, and what is provided by the suppliers tend to be biased and distorted. Research within how risk related data can be retrieved via external sources or from the suppliers in an unbiased manner is required.

Secondly, additional research within the correlation between investments made in new risk management tools and financial savings is required. Multiple interviewees claimed they would gladly invest in new risk management tools if a business case could be built to support it. This would require in-depth analyses of how the benefits of implementing these new systems outweighs the incurred cost.

Lastly, as more and more risk factors are included when conducting risk assessment, the complexity also increases. Evaluating too many risk factors manually is simply not an option in most purchasing organizations. Hence, additional research is required in how software can assist in the risk assessment process using tools like machine learning and AI.

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Appendix: Risk identification workshop template

Risk Identification Workshop

Purpose

The purpose of this workshop is to identify the challenges and risks originating from Aptiv's supplier base, and which risks are the most critical according to the workshop participants. Additionally we aim to discuss potential mitigation strategies for a selection (2-3) of the prioritized risk areas.

Workshop goals

- Identify critical risk areas originating in Aptiv's supplier base
- Prioritize identified risk areas
- Propose high-level mitigation strategies for prioritized risk areas

Workshop agenda

1. (5 min) Brief overview of the workshop's purpose and goals.
2. (10 min) Individual task: Try to capture as many supplier related risks as you can think of. You are encouraged to use risk categories presented on the back of this page to enable wider thinking. Write the risks on the post-it notes in front of you (one risk/post-it).
   For example:
   - "Long lead times when sourcing subassemblies"
   - "Too late PPAP approvals"
3. (15 min) Briefly share with the others the three most important risk areas you have identified and place these post-it notes on the whiteboard, under the appropriate risk category.
   If duplicates occur: place the post-it notes on top of each other.
4. (10 min) Group discussion:
   - (5 min) Which of the risk areas on the whiteboard are the most critical for Aptiv, and why?

- (5 min) Which of the risk areas on the whiteboard are the most critical for OEMs, and why?

5. (5 min) Individual risk prioritization. Each participant is assigned 6 colored dots (3 red & 3 green). Individually place the dots on the whiteboard on your prioritized risks:
   - Red: high priority for Aptiv
   - Green: high priority for OEM
6. (10 min) Discuss and develop potential high-level mitigation strategies for the prioritized risk areas.

Risk categories:

Disruptions/disasters - Such as natural disasters, labor disputes, production facility breakdowns, supplier bankruptcy and political unrest.
Logistics - Risks related to movement of goods, such as delivery performance, lead time, transportation capacity, infrastructure issues and number of transfer points.
Supplier dependence - Uniqueness of product and/or competencies.
Quality - Issues with quality of sourced products and ease of problem resolution.
Information systems - Information sharing internally and with suppliers.
Forecast - Demand forecasting inaccuracies resulting in supply issues such as stockouts, excessive backlog and last-minute order adjustments.
Financial - Financial health of supplier, exchange rate risk and financial stability in the region.
Legal - Legislative actions related to importing/exporting.
Intellectual property - Supplier's reluctance to share proprietary knowledge.
Procurement - Contract compliance, length of contract, single-sourcing.
Capacity - Supplier's manufacturing capacity and availability of workforce.
Security - IT system breakdowns, theft of physical goods and/or intellectual property.