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Master Thesis

Supply chain risk analysis of company X: "Risk management tool for supply chain risks"

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Abstract

Purpose – The purpose of this research is to develop a supply chain risk management tool that can measure/assess and monitor risk in the supply chain. Additionally, this research redesign assessment and monitoring models for the automotive company in the Netherlands.

Design/methodology/approach – This business research uses multiple methodologies to solve the business problem for company X. First, the problem solving methodology of Aken et al. (2012) was used during the process. The supply chain-risk literature is then further analysed and several interviews in combination with the business documentation are used for identifying the SC risks, with the aim developing a risk management tool.

Findings –The risk management tool is constructed based on a probability–impact matrix and a multi-criteria scoring procedure. This risk management tool calculates the risk degree of each identified risk and monitors these risks over time with weights. The risk management tool is a visual construct so it is easy to understand under which risk level the company operates.

Research limitations/implications – This research has some limitations. One issue was time limitation; this results in that the research focused only on main supply chain risks with disruptive potential.

Practical implications – The risk management tool was constructed especially for company X to measure its supply chain risk. There is a possibility to introduce this model to other industries if the risk identification and risk categories match a company's requirements.

Originality/value – This research redesign two methods to assess and monitor risks in the supply chain and implement the risk results in a colour visual manner.

Key words- Supply chain risk management, Supply chain risk, Risk management process, Risk assessment, Risk management, Automotive industry

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Index of abbreviation

SC	Supply chain
SR	Supply risk
RM	Risk management
SM	Supply management
OEM	Original equipment manufacturer
ERP	Enterprise resource planning
SCR	Supply chain risk
SCRs	Supply chain risks
SCM	Supply chain management
SCRM	Supply chain risk management
SCMP	Supply chain management process
SCRMT	Supply chain risk management tool

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1. Growing supply chain risk and uncertainty have drawn increased attention to company X's approach to supply chain

1.1 Background to company X' situation

Given the increasing vulnerability of supply chains, supply chain risk management (SCRM) is of growing importance.[1] There is a need for firms to manage their supply chains effectively to increase efficiency and reactivity.[2] Before discussing supply chain risk (SCR) and its impacts for the purposes of this study, it is necessary to provide a clear definition of this term.

Risk can be defined as 'the extent to which there is uncertainty about whether potentially significant and/or disappointing outcomes of decisions will be realized'.[3] Supply chain risk is defined as 'the probability of an incident associated with inbound supply from individual supplier failures or the supply market occurring, in which its outcomes result in the inability of the purchasing firm to meet customer demand or cause threats to customer life and safety'.[4]

Company X, which is located in the Netherlands, is a market leader in motion control systems. Its specialised high-quality products include hydraulic actuation systems for a large number of applications in the automotive, truck, medical, marine, and off-highway industries.[5] Because of the diversity of its products, markets, and suppliers, SCRM has become an increasingly important issue for this company. The purchasing department, which carries most of the responsibility for the company's supply chain, is confronted with a number of risks. These include insufficient capacity on the part of suppliers, delays in the supply chain, product quality issues, and poor communication with suppliers. A secondary problem is that the purchasing department lacks a structured and systematic approach to identifying, measuring, and mitigating these risks.

One of the company's purchasing managers stated that its purchasing professionals currently have little insight into the SCRM process. In addition, the purchasing director confirmed the company's lack of capacity with regard to mapping and managing SCR. As such, both purchasing managers and other professionals at company X have expressed increasing interest in SCRM systems. The interest on the part of the purchasing department is high because the purchasing function is a vital component of a firm's SCM efforts.[6]

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[1]Norrman and Jansson (2004, p. 434)
[2]See Thun and Hoenig (2011, p. 242)
[3]See Sitkin (1992, p. 10)
[4]Zsidisin (2003, p. 222)
[5]"Power- Packer Company Profile" 2017 "unknon author")
[6]Giunipero and Brand (1996, p. 32)

Moreover, Hoffmann (2012) states that it is important for companies to know which risk sources exist in their supply chain for a better performance.[7]

Company X therefore intends to implement a comprehensive SCRM system to assess and monitor SCRs. To this end, the current study reviews a variety of SCRM models to determine which would best fit the company. The following sections detail the purpose of this research and present the research questions.

1.2 Aim of this research: developing a supply chain risk tool that asses and monitors supply chain risk

This section introduces the main aim of this research, the focus of which is on reviewing the distinct phases of SCRM: identifying, assessing, mitigating, and monitoring risks.[8] Based on the available academic literature, this study identifies SCRs and redesign assessment and monitoring models that are suitable for company X. With the aim of developing a systematic and structured risk management tool, this study also investigates and describes the SC risks for company X, different risk approaches, and the phases of the SCRM process in terms of the company's present situation.

A further aim of this research is to identify new approaches or gaps in the field of SCRM in order to make a contribution to this field of study. For example, this research discuss the supply chain risk management process in detail for an automotive industry in the Netherlands, since the limitation of practical SCRMP approaches/papers. The aim is identifying risk and developing a risk management tool based on existing assessing and monitoring risk methods that is previously used in German and USA automotive industries. Because, the industries (automotive) are the same and the goal is to implement a risk assessment and monitoring models in a SCR tool that fits by the company. Additionally, there is also a gap/limitation about monitoring methodology,[9] this research discuss and implement a monitoring methodology in detail. In consultation with both the researcher's academic supervisors and professionals working for the company, the following business problem aim has been formulated:

'To develop an SCRM tool for assessing and monitoring SCR in the automotive industry in the Netherlands'.

[7]Hoffmann (2012)
[8]See Hallikas et al. (2004, p. 52)
[9] (Blackhurst et al., 2008)

1.3 The 'business problem' translated into a set of research questions

The above section describes the current 'business problem' for company X. For the researcher to be able to present a solution, the business problem has to be translated into a research question and sub-questions regarding an SCRM tool.

The main research question is as follows:

How can company X asses and monitor supply chain risks?

The following sub-questions were developed to help answer the main research question:

1.1 What are the SCRs for company X?

1.2 Which SCR assessment model is applicable for company X to assess supply chain risks?

1.3 How can company X continuously monitor SCRs?

Several requirements were discussed so that optimal support is provided for the procurement department of Company X. The following requirements were formulated:

-The tool should be easy to use
-The tool should assess and monitor SCR
-The tool should be based on a theoretical framework

To achieve the research aim the remainder of this paper is organised as follows. The following chapter reviews the research literature on managing SCR and approaches. Section 3 presents the methodology and describes its use. Section 4 discusses the results of the research. Section 5 examines the development of the risk management tool for company X. Finally, the researcher presents her conclusions and further research and limitations of the methodology in Sections 6 and 7.

2 Review of the literature on supply chain risk, supply chain risk management, and approaches in supply chain risk management

This chapter reviews the literature on supply chain risk. The academic interest, purpose of the literature review, definitions of SCRs, supply chain risk management process phases, supply chain risk categories, supply chain risk classification and empirical SCRM approached will discussed in this chapter.

2.1 Increased academic interest in supply chain risk management in recent years

Increased SCR led to the rise of SCRM as a research topic in academic circles.[10] Risks such as earthquakes, economic crises, political issues, terrorist attacks, or quality problems can repeatedly disrupt supply chain operations.[11] These disruptions can have a significant impact on a firm's short-term performance.[12] Well-known examples include Ericsson's 400 million-euro loss after a plant fire in 2000 and the earthquake that struck Taiwan in 1999.[13] Actually, SC disruptions can arise from many sources, including risk sources as natural disasters and risk sources such as quality problems in the supply chain.[14]

According to Pujawan and Geraldin (2009), 'to survive a risky business environment, it is crucial for companies to have a proper SC risk management'.[15] Faisal et al. (2006) state that the risk management process is focused on understanding risks and minimizing their impact by considering, for example, their probability and direct impact(s).[16]

Figure 2.1 shows SCRM-related academic studies published between 1972 to 2018. The results presented below were obtained from Scopus by searching for combinations of the keywords of supply chain and SCRM or SCR assessment.

Figure 2.1 indicates that the academic interest in SCR primarily increased from 2002; it also shows that the number of publications increased from 22 (2002) to 338 in 2018. Overall, academic interest in SCRM is growing rapidly, and this concept has become an important topic in the field of SCR. Therefore, this research investigates the SCR situation in the Netherlands' automotive industry.

[10]See Hendricks and Singhal (2005, p. 35) and Thun et al. (2011, p. 5511) and see Trkman and McCormack (2009, p. 255)
[11]See Manuj and Mentzer (2008, p. 134); Tang (2006a, p. 452; 2006b, p. 33)
[12]See Tang (2006a, p. 452)
[13]See Norrman and Jansson (2004) Tang (2006a, p. 452) and Yu et al. (2008, p. 788) and see Chopra and Sodhi (2004, p. 53)
[14]Ponomarov and Holcomb (2009, p. 125)
[15] Pujawan and Geraldin (2009, p. 954)
[16]See Faisal et al. (2006, pp. 535-534)

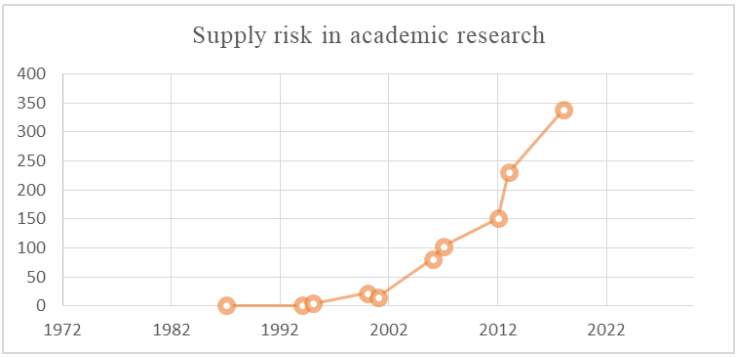

Fig. 2.1: Overview of publications on SCRM.
Data source: Scopus. Table created by researcher.

The literature considered in this research includes scientific journals and management books. In addition, Scopus or Google Scholar were consulted using the following search terms: supply chain, supply risk management, supply risk, supply risk assessment, supply chain disruptions, supply chain risk assessment tools, risk assessment, supply chain risk management process.

2.2 Purpose of the literature review in this study

Sources from the literature play several roles in this thesis. This section describes the various uses of the findings of the literature review in this research this section explains the different purposes of using the literature review.

First, this research conducted a literature review to understand and explain terms, concepts, and definitions related to SCR. The researcher consulted various sources to obtain quotes from academic authors focused on the field of SCRM.

Second, to answer the sub-questions, the researcher needed to understand and investigate the SCR theory, assessment models, modelling techniques, and approaches found in the academic literature. The information obtained from the academic literature is used to create a tool capable of assessing and monitoring SCR for company X.

Furthermore, the researcher also compared risk assessment approaches and techniques from various authors to identify a suitable risk assessment tool for company X.

In summary, the literature review serves as a backbone of the business research to develop an SCRM tool for company X.

2.3 Definitions of supply chain risk management terms

The sections above describe the current business problem. To understand the entire problem, definitions of different terms in the field of SCR are needed. The aim of the approach is for the reader to easily understand the terms of SCR and/or return to the section if they need clarification of the terms.

"Risk 'is the chance, in quantitative terms, of a defined hazard occurring"'.[17]

"Supply chain 'a network of connected and interdependent organisations mutually and co-operatively working together to control, manage and improve the flow of materials and information from suppliers to end users"'.[18]

"Supply risk 'the probability of an incident associated with inbound supply from individual supplier failures or the supply market occurring, in which its outcomes result in the inability of the purchasing firm to meet customer demand or cause threats to customer life and safety '".[19]

"Supply chain management 'the integration of business processes from end user through original suppliers that provides products, services, and information that add value for customer"'.[20]

"Supply chain risk management 'the identification and management of risks for the supply chain, through a co-ordinated approach amongst supply chain members, to reduce supply chain vulnerability as a whole"'.[21]

"Vulnerability 'an exposure to serious disturbance, arising from risks within the supply chain as well as risks external to the supply chain"'.[22]

"Environmental risk 'sources comprise any uncertainties arising from the supply chain environment interaction. These may be the result of accidents (e.g. fire), socio-political actions (e.g. fuel protests or terrorist attacks) or acts of God (e.g. extreme weather or earthquakes)"'.[23]

[17]Norrman and Jansson (2004, p. 436)
[18]Christopher (2011, p. 4)
[19]Zsidisin (2003, p. 222)
[20]Cousins et al. (2008, p. 174)
[21]Juttner (2005, p. 124)
[22]Yu et al. (2008, p. 789)
[23] Jüttner et al. (2003, p. 11)

2.4 Supply chain risk management phases in the academic literature: risk identification, assessment, mitigation, and monitoring

The academic literature shows that SCRM typically consists of four phases.[24] Before the development of an SCRM tool, the SCR phases need to be explored (see Figure 2.4 for an overview of the SCRM process). The phases of the SRCM process are depicted in a circular fashion. The risk management process is a circular approach for continuously improvements (see Appendix I and the approach of (Norrman & Jansson, 2004)). The SCRM process is discussed separately in the next sections.

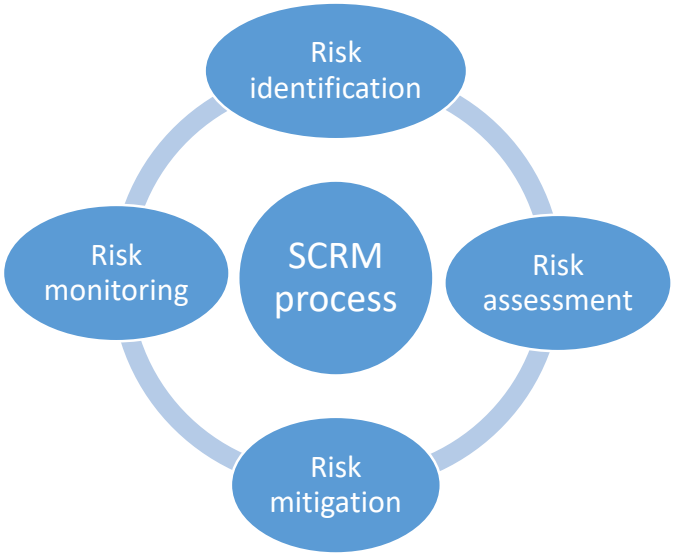

Fig. 2.4: Risk management phases

Source: Hallikas et al. (2004); Hoffmann (2012); Norrman and Jansson (2004)

Phase 1: Risk identification

Risk identification is arguably the most critical step in SCRM.[25] According to De Oliveira et al. (2018), 86.9% of the relevant literature indicates that 'risk identification' is the first step in the supply chain risk management or supply-risk process.[26] Risk identification uncovers potential risks, taking into consideration the 'bigger picture of all potential risk and risk events'.[27] Hence, companies must accept the fact that only identification of risks can lead to any further risk management activity.[28] Therefore, identifying SCRs is necessary, as it can provide more awareness and insights in SCRs. It also promotes a firm's awareness of SCR and

[24]See Hallikas et al. (2004, p. 52)
[25]See Kleindorfer and Saad (2005, p. 56)
[26]See Hallikas et al. (2004); Hoffmann (2012, p. 80); Kleindorfer and Saad (2005)
[27]See Buhman et al. (2005, p. 504)
[28]See Kern et al. (2012, p. 63)

increases the probability that it will take relevant actions in the SC.

The academic literature describes various methods for identifying SCR. For example, Norrman and Jansson (2004) present two commonly used techniques, namely fault tree analysis (FTA) and event tree analysis (ETA).[29] Both of these approaches logically present the sequence of failures that may spread through a complex system.[30] Kern et al. (2012), however, suggest that the major focus should be on identification of each relevant risk, with the causes and effects of each being identified.[31] In addition, Hoffmann (2012) discuss the World Café method in her research to identify risks, in which respondents form small discussion groups to explore potential SCRs.[32] Finally, it is important to note that only those risks that are identified in the first step can be assessed and managed in the subsequent phases of the SCRM process.[33]

Phase 2: Risk assessment

Risk assessment is the second step of SCR. It involves evaluation or calculation of the probability of an unexpected risk and its impact(s).[34] In practice, understanding the risk factors in the assessment process leads to better preparation for a specific risk and provides useful information about the risk. For example, risk assessment results shows whether the identified risk is high or low, then the analyst can summary an overview with important risks that needs to mitigate in the further phases. Risk assessment phase ensures overview and shows the risk degree of an identified risk. The academic literature provides a variety of approaches to assessing risk, probability, and business impacts for example, (see Figure 2.4.1 and 2.4.2). According to Thun and Hoenig (2011), after risk identification, a risk should be assessed in terms of its probability of occurring and the extent of its potentially adverse effects on a company's supply chain.[35] Thun and Hoenig (2011) used the probability impact matrix to assess the SCR of an automotive company in Germany (see Figure 2.4.1). Norrman and Jansson (2004) employed a similar matrix for risk assessment following the risk identification phase (see Figure 2.4.2).[36]

[29]See Norrman and Jansson (2004, p. 438)
[30]See Norrman and Jansson (2004, p. 438)
[31]See Kern et al. (2012, p. 64)
[32]See Hoffmann (2012, p. 81)
[33]See Berg et al. (2008)
[34]See Hallikas et al. (2004, p. 53);Tuncel and Alpan (2010, p. 251);Harland et al. (2003, p. 53) as well as Wagner and Bode (2009, p. 16)
[35]See Thun and Hoenig (2011, p. 244)
[36]See Norrman and Jansson (2004, p. 437)

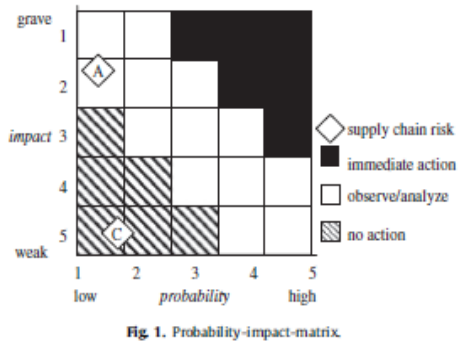

Fig. 2.4.1: Probability– impact matrix
Source: Thun and Hoenig (2011), p. 244

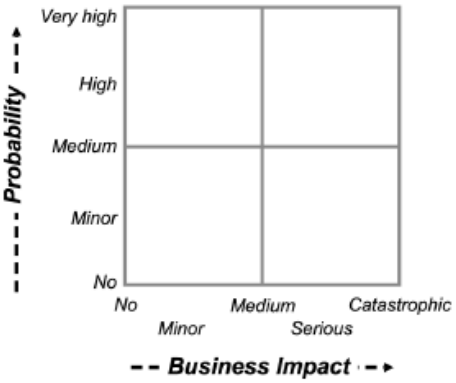

Fig 2.4.2: Risk map/matrix
Source: Norrman and Jansson (2004), p. 437

Norrman and Jansson (2004); Thun and Hoenig (2011) indicate that it is necessary to assess and prioritise risk to be able to choose the most appropriate management actions in a given situation. Risk assessment model Figure 2.4.1 measures the probability and business impact of each identified risk by assigning it a rating from 0 to 5, where 0 represents low risk and 5 high. Each individual risk must be rated separately based on probability and business impact; thereafter, the risk assessment model indicates the importance of each identified risk and indicates the urgency of an incident before it occurs.[37] Figure 2.4.1 and 2.4.2 present two different measurements approaches, but, according to Thun and Hoenig (2011), the exact qualification of risk values is often difficult; as a precise assessment of the probability of occurrence and the effect(s) of a risk is hardly possible, it is advisable to at least evaluate an identified risk in a qualitative way.[38] According to Chang et al. (2015), 'evaluation of risk is necessary for assessing appropriate SC mitigation strategy because, as posited by contingency theory, risk contexts can determine appropriate approaches for mitigation'.[39]

Hallikas et al. (2004) confirmed that risk assessments are required in order to choose suitable management actions for addressing identified risk factors.[40] When SCRs are assessed, the company in question becomes more aware of critical risks and can then take action to mitigate them. Hallikas et al. (2004) also represent the two components of risk, namely probability and the consequences of a risk event.[41]

[37]See Thun and Hoenig (2011, p. 245)
[38]Thun and Hoenig (2011, p. 244)
[39]Chang et al. (2015, p. 644)
[40]See Hallikas et al. (2004, pp. 52-53)
[41]See Hallikas et al. (2004, p. 53)

Phase 3: Risk mitigation

The third phase in the SCR process is 'risk mitigation', which entails formulating a plan of action to counteract the risks defined in the identification phase.[42] According to Stecke and Kumar (2009), 'mitigation strategies could be critical for the survival of a company'.[43] There are a number of examples of mitigation strategies in the academic field of supply chain research, including the 'classics' of multiple sourcing, increased flexibility, pooled demand, supplier development, supplier early involvement, information sharing, and establishing trust among supply chain partners.[44] For example, Hahn et al. (2000) state that effective communication and coordination among the parties involved in a SC are essential to its success.[45] Chopra and Sodhi (2004) suggest that transparently sharing information across a supply chain minimizes risk. According to Christopher (2000), information sharing is becoming ever more prevalent in the supply chain for a confident relationship in an agile supply chain.[46]

For each identified risk, a suitable mitigation strategy, which can be either proactive or reactive, is necessary. Reactive mitigation strategies come into play when an undesirable event occurs; such strategies include insurance and buffering approaches. Although such strategies do not prevent risks, they provide 'cover' in the event of a risk manifesting as a negative event. In contrast, proactive mitigation strategies work actively to prevent negative effects; examples of such strategies include multiple sourcing or avoiding countries that are known to have problems.[47] Wieland and Wallenburg (2012) indicate that proactive (i.e. robust) and reactive (i.e. agile) supply chain strategies reduce the vulnerability of a supply chain and are thus essential.[48] Agility is a reactive approach and is mostly understood as referring to the ability of a supply chain to rapidly respond to change by adapting its initial stable configuration.[49] In contrast, robustness is a proactive approach that can be defined as 'the ability of a supply chain to resist change without adapting its initial stable configuration'.[50] For example, multiple sources of supply make a supply chain more robust, as the flow of material will be sustained even if the flow of material from supplier A is

[42]See Kern et al. (2012, p. 65)
[43]Stecke and Kumar (2009, p. 207)
[44]See Braunscheidel and Suresh (2009, p. 120) and See Chopra and Sodhi (2004, p. 55)
[45]See Hahn et al. (2000, p. 34)
[46]See Christopher (2000, p. 39)
[47]See Knemeyer et al. (2009); Norrman and Jansson (2004) and Zsidisin et al. (2000)
[48]See Wieland and Wallenburg (2012, p. 888)
[49]See Christopher et al. (2006, p. 281 and 283)
[50]Wieland and Wallenburg (2012, p. 890)

disrupted.[51] In contrast, agile approaches primarily correspond with being responsive.[52] Examples of agile strategies are supplier/buyer communication and making to order/postponement.[53] Ghadge et al. (2012) prefer a proactive (58.33%) over a reactive (23.33%) approach to risk mitigation.[54] Rajesh et al. (2014) indicate that proactive approaches require more attention to be devoted to dealing with changing risks and vulnerabilities in covering a supply chain, particularly in supply chains that are lengthier and more complex as a result of globalisation.[55]

Chopra and Sodhi (2004) focused on supply risk management, risk mitigation strategies, and the interconnectedness of supply risk. It is generally accepted that preventing SCR entirely is not possible; as Chopra and Sodhi (2004) note, 'there is no silver-bullet strategy for protecting organisational supply chains'.[56] Instead, managers need to know which mitigation strategy works best against a given risk. This requires understanding SCR and supply chain remedies.[57] Figure 2.4.3 presents mitigation strategies that affect SCR sources, while Table 2.4.3 shows the probable effect(s) of mitigation strategies on other risk sources. For example, storing extra inventory in warehouses, having redundant suppliers for critical items, and increasing flexibility within a company are mitigation strategies.[58] Table 2.4.3 indicates that using different mitigation strategies could have a range of effects on a supply chain; it also indicate with arrows the probable effect of using mitigation strategies on increasing or decreasing risk in the SC.

[51]See Tang (2006b)
[52] (Christopher et al., 2006)
[53]Norrman and Jansson (2004) and Swaminathan and Lee (2003)
[54]Ghadge et al. (2012, p. 324)
[55]See Rajesh et al. (2014, p. 1) and
[56]See Chopra and Sodhi (2004, p. 55)
[57]See Chopra and Sodhi (2004, p. 55)
[58]See Chopra and Sodhi (2004, p. 55)

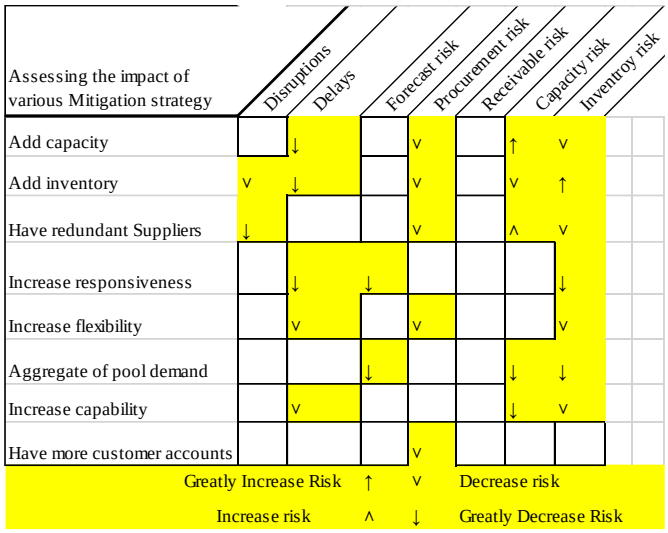

Fig. 2.4.3. Mitigation strategies
Source: Chopra and Sodhi (2004, p. 55)

According to Chopra and Sodhi (2004), adding flexible capacity such as employees who can work on any station in an manufacturing company or being able to serve geographically scattered customers will reduce delays in a supply chain. However, the likelihood of increasing capacity risk as a result of using such strategies is high. For example, a case in 2000-2003, when many semiconductor firms had to operate at about 50% capacity because of soft demand.[59] Thus, by understanding the variety and interconnectedness of SCRs, managers can tailor balanced, effective risk-reduction strategies for their companies.[60]

Phase 4: Risk monitoring

The majority of the SCRM models in the academic literature neglect the risk-monitoring phase.[61] Risk monitoring ensures early warning of potential risk-related situations and gives companies time to react to changing circumstances, thus allowing them to refine their mitigation strategies. [62]

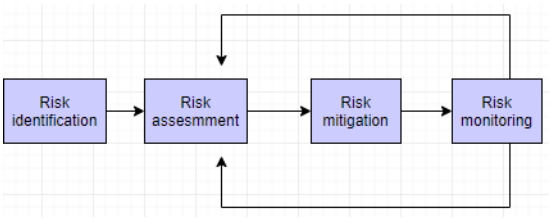

Fig. 2.4.4: Risk monitoring approach
Source: Hallikas et al. (2004) and Norrman and Jansson (2004)

[59]See Chopra and Sodhi (2004, p. 59)
[60]See Chopra and Sodhi (2004, p. 53)
[61]See Blackhurst et al. (2008, p. 146)
[62]Wagner and Bode (2009)

Hallikas et al. (2004) and Norrman and Jansson (2004) treat the monitoring phase as part of regular 'risk identification and assessment' (see Figure 2.4.4). These authors indicate that continuous repetition of risk assessment ensures effective risk monitoring. It is worth mentioning, however, that risk monitoring is time-consuming; it is therefore not beneficial to consider the entirety of a supply chain in this activity.

In their recommendations for automotive companies, Blackhurst et al. (2008) suggested a risk assessment and monitoring system with a multi-criteria scoring procedure to track situations involving risk over time.[63] They calculated risk values with scores for various aspects of the supply chain, including 'defects/million', 'product complexity', and 'supplier bankruptcy'. These risk aspects are monitored over time and are used in the generation of 'heat graphs' that indicate the levels of risk.[64]

2.5 Supply chain risk categories

Before developing an SCRM process, firms need to understand supply chain interdependencies and identify potential SCR factors/triggers, their likelihood and consequences.[65] According to Blackhurst et al. (2008), to assess risk in a supply chain, risk categories must first be specified.[66] Tummala and Schoenherr (2011) mentioned that a list of SCRs should be created to allow for a structured and systematic approach to assessing risk severity and likelihood.[67] Furthermore, Hoffmann (2012) indicated that only the use of adequate indicators to monitor risks will reduce risk- related problems.[68] Tummala and Schoenherr (2011) mentioned that SCR triggers adversely affect supply chain operations and hence supply chain performance.[69] Thus, identification of the SCR categories for company X is necessary in this process.

Table 2.6 presents SCR triggers/categories obtained from different studies, most notably those of Chopra and Sodhi (2004), Blackhurst et al. (2008); Schoenherr et al. (2008); Tummala and Schoenherr (2011).[70] Based on the findings of these studies, the Appendix XI presents the important risk triggers/categories for company X.

Blackhurst et al. (2008) present the risk categories and subcategories for the automotive industry in order to assess and monitor supply risk, while the works of Chopra and

63See Blackhurst et al. (2008, p. 144)
[64]See Hoffmann (2012, p. 85)
[65]See Chopra and Sodhi (2004, p. 54)
[66]See Blackhurst et al. (2008, p. 149)
[67]See Tummala and Schoenherr (2011, p. 474)
[68]See Hoffmann (2012, p. 81)
[69]See Tummala and Schoenherr (2011, p. 474)
[70]See Chopra and Sodhi (2004, p. 54) and See Schoenherr et al. (2008, p. 106)

Sodhi (2004) and Tummala and Schoenherr (2011) are similar, as both summarise the SCR of an individual firm.

Finally, the main goal of this theory is understanding and identifying the main source of risk and to understand the universe of risk categories as well as the events and conditions that drive them.[71] Then, with the specific information and knowledge about the SC risks, companies can proceed to select a tailored mitigation strategies likely to be most effective. The risk categories in table 2.6 will used later in the risk management tool at monitoring phase as (Blackhurst et al., 2008) mentioned. The risk categories are selected on basis of industry segment and aspects that fits the best with the problem of company X. Company X can assess and monitor per risk category the progress with the risk management tool.

Risk categories	**Subcategory**
Quality	Value of product
	Ease of problem solution
	Timeliness of corrective actions/responding
	Defects of million
Manufacturing risk	Changes in product design
	Machine breakdown
	Supplier material
Supplier dependence	Supplier manufacturing capacity or flexibility of supply source
	Dependence on a single source of supply
	Location
Procurement	Exchange rate risk
	Part price
	Long term versus short term contracts
Disruptions/disasters	Earthquake, flooding, and terrorism
	Transport/delivery
	External automotive requirements

Table 2.5 risk categories
Source: Tummala and Schoenherr (2011, p. 475) and see also Chopra and Sodhi (2004)

2.6 Classification of supply chain risks

Classification of supply chain risk is different than categorisation. Classification of risk shows the source of the risk for example, internal or external classifications. Categories, categorise the risk in sub categories and go deeper in risk variables (subcategories). The basis of good SCRM starts with understanding of what kind of risk sources exist in the SC. Supply

[71]See Chopra and Sodhi (2004, p. 54)

chain risk management is a very broad topic; in order to define risks more precisely, Trkman and McCormack (2009) suggest classifying risk based on various aspects.[72]

Tang (2006a) described operational and disruption risks in his research. Operational risk refers to uncertainties arising concerning supplier quality or as a result of supply or demand in a chain.[73] Disruption risks, in contrast, include terrorist attacks, floods, and earthquakes. Hunter et al. (2004) categorised risk based on its probability and importance, which is very similar to the approach of Hallikas et al. (2004). In addition, Trkman and McCormack (2009) described endogenous uncertainty and exogenous uncertainty, which are similar to the internal and external risk descriptions of Tang (2006a); Thun and Hoenig (2011). External risks are those that a company has no influence over; these can be called 'uncontrolled risks', with examples including natural disasters or currency fluctuations, while internal risks are 'managed risks', such as quality problems with a supplier.[74]

Clear classification is important due to the various mitigation approaches adopted for different risk sources. Internal risk, also called endogenous uncertainty, can be reduced through establishing a formal and proactive relationship with a supplier (Trkman & McCormack, 2009). Examples of approaches that can be adopted to reduce internal risk are: information sharing, performance improvement, and relationship development (Ritchie & Brindley, 2007).[75] External risk, also called exogenous uncertainty, cannot generally be reduced by developing a proactive relationship, but hiring an insurance company would be a possible solution.

[72]See Trkman and McCormack (2009, p. 249)
[73]See Tang (2006a, p. 453)
[74]Abdel-Basset et al. (2018)
[75]See Ritchie and Brindley (2007, p. 310)

2.7 Empirical approaches to the supply chain risk management process in the telecom and automotive industries

The theory of SCRM is discussed in the previous chapters. This section discuss the empirical SCRM approaches of different industries. This chapter ensures practical examples about SCRM process and approaches of different authors in the automotive branch and electronic branch. Empirical approaches provide also better understanding about the goal and subject SCRM, and helps the reader to keep the storyline of this thesis.

2.7.1 Ericsson's supply chain risk-assessment approach

Since the fire disruption at a sub-supplier, with a huge impact on Ericsson of its supply chain, Ericsson has implemented systems and tools to enable better SCRM. The company has introduced the basic risk processes in its SCRM (see Figure 2.8.1).[76] The aim of the approach is to minimise risk exposure in the supply chain. This SCRM approach is based on a process that features feedback loops among its sub-processes. The processes include risk identification, assessment, treatment, and monitoring.[77]

The corporate SCR approach brings various players, along with their differing responsibilities, into risk management. For example, purchasing and logistic functions are involved in the process and examined with respect to different areas. Ericsson's approach is to work in a matrix-oriented way, in which, for example, corporate risk management has the overall responsibility, core unit supply has the responsibility for operative work, and delay interfaces with suppliers. The system business area (SBA) has the business perspective and owns the product. This approach ensures that various departments are involved and share responsibility for implementing and monitoring information about SCR see Figure 2.8.2 for the risk corporate-level approach).[78]

Fig. 2.8.1: Ericsson's basic supply chain risk approach
Source: Norrman and Jansson (2004, p. 442)

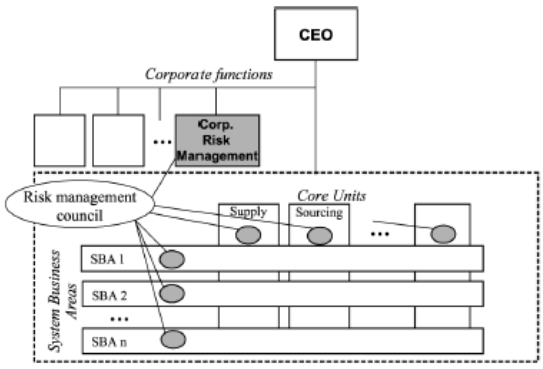

Fig. 2.8.2: Ericsson's corporate approach
Source: Norrman and Jansson (2004, p. 443)

[76]See Norrman and Jansson (2004, p. 442)
[77]See Norrman and Jansson (2004, p. 442)
[78]See Norrman and Jansson (2004, pp. "p. 442-444".)

2.7.2 The supply chain risk approach in the automotive industry

The purpose of this approach is managing risk in a supply chain by weighting the relative risks. Blackhurst et al. (2008) used a multi-criteria scoring procedure to calculate risk in the supply base.[79] They state that, rather than monitoring risks, most SCRM studies focus on categorising and assessing risks to predict and mitigate them[80] This gap is a problem, because as mentioned earlier, risk monitoring ensures early warning of potential risk-related situations and gives companies time to react to changing circumstances, thus allowing them to refine their mitigation strategies. [81] The approach adopted by Blackhurst et al. (2008) to monitoring the supply base involves various steps, which begin with the categorising of risk. For example, 'disruptions/disasters' is a risk category, which is further divided into subcategories such as 'labour dispute', 'supplier bankruptcy', and 'war and terrorism'.[82]

Furthermore, the risk categories and subcategories are weighted according to multi-criteria scoring requirements to indicate their relative importance in terms of the 'parent' category. The weights indicate how important each subcategory is in the parent risk category. The weights of each subcategory can be used to determine the likelihood per risk subcategory. Blackhurst et al. (2008) used a multi-criteria scoring model to calculate all risk assessment scores, for example, multiplying each supplier's rating on that subcategory by the percent of production purchased from that supplier to determine the individual supplier score on that risk category.

This procedure is applied to all risk categories in the company.[83] When the risk assessment data are completed and calculated, the results can be entered into a heat graph, the concept of which is similar to Norrman and Jansson (2004) risk-assessment method. The graphs have similar colours to those used in the Norrman and Jansson (2004) model for indicating risk level, allowing a risk manager to focus quickly and easily on high risk scores.[84] Appendix IV displays the supplier risk assessment and monitoring approach of Blackhurst et al. (2008) for the automotive industry.

[79]See Blackhurst et al. (2008, p. 145)
[80]See Blackhurst et al. (2008, p. 146)
[81]Wagner and Bode (2009)
[82]See Blackhurst et al. (2008, pp. "148-149")
[83]See Blackhurst et al. (2008, pp. 149-150)
[84]See Blackhurst et al. (2008, p. 153)

2.8 Supply chain risk management models in the literature ensure a new approach in the risk management tool for company X.

This research redesign the four phases of SCRM; identification, assessment, mitigation and monitoring for company X (see Section 2.4). Redesign in this research means, using existing SCRM models from academic theory and further implemented in a different manner in a risk management tool. For example, adding new options or adjusting the models according to company requirements. The origin of the theory is still included but the models are adjusted to company requirements. This research focusses mainly on redesigning of assessment and monitoring methods used previously by authors in the automotive industry, namely the probability–impact matrix of Thun and Hoenig (2011) and the multi-criteria scoring procedure of Blackhurst et al. (2008). These models are described in research papers on SCRM in the automotive industry. However, Thun and Hoenig (2011) described an empirical analysis of SCRM in the German automotive industry, and Blackhurst et al. (2008) developed a risk assessment and monitor approach for the automotive industry in the USA.

The reason for this approach is that both risk assessment and risk monitoring are used in the automotive industry in Germany and USA. It is interesting to redesign the models and further implement in the automotive industry in the Netherlands to cover the gap of limited practical academic papers and to answer the research question of this study. Hereby, company X can easily measure risk level and respond in a timely manner to reduce or avoid SC disruptions. Both approaches are necessary to develop a risk management tool for company X. There are several reason why these models become together. The overlap and relation between these two models are the quantitative method approach. Both method assess and monitor SC on basis of quantitative scores. Therefore, interpretation would be easier because of using the same method to assess and monitor SCRs. Additionally, interpretation is easy and presenting the results have the same structure. Therefore, the colours in both models have the same meaning. Other important aspect is that the risk assessment model that is used is less detailed in contrast to monitoring model that is used. The monitoring tool assessed the risk again after the mitigation strategies based on categories. Hereby the level of risk is determined two times and will be monitor in the future. This combination of two models provides additional information about SCRs and ensures extra control in the SC. However, the first risk assessment indication is necessary to develop a tailored risk mitigation strategies in the third step to counter act the potential risks.

Furthermore, the risk management tool based on Blackhurst et al. (2008); Thun and Hoenig (2011) models provides an overview of a number of risk that must be further

considered in the risk management tool. For example, the multi-criteria scoring procedure method monitors the scores for risk categories in a supply chain. The methodology takes data and converts them into a visual form that is appropriate for SCRM, making it possible to monitor the level of SCR with the aim of identifying risks sooner and thus reducing their impact on a supply chain.[85] The automotive industry is very strict, and quality requirements are important; hence, considering all critical risk factors is essential for the firm. Managers can use the tool as a first step in the SCRM process to minimise potential disruptions impacts to the supply chain. In addition, managers can also avoid disruptions before they occur or, at the very least, lessen their impact by using the risk management tool frequently.

Moreover, monitoring risk proactively and regularly is important (Blackhurst et al., 2008; Hallikas et al., 2004; Hoffmann, 2012; Norrman & Jansson, 2004). Thus, the SCRM tool is structured in such a way that company X can easily assess and monitor its own SCR through the use of this tool. In the future, company X will be capable of assessing and monitoring potentially critical risks. The risk management tool is easy to use and applicable to both SCR and supplier risk. Chapter 5 elaborates on the process of the tool's development, because it is necessary to specify on how the tool is built for further approaches. It is also important to discuss how company X can use the tool and by who. It gives the employees a guidance in their work. It is a good way to record work agreements, so that everyone knows what has been agreed (and why). Finally, to be able to perform activities better, it is necessary to first gain insight into the content and performance of a process, and process control provides this insight.

[85]Blackhurst et al. (2008, p. 145)

2.9 Summary of findings concerning current supply chain risk management models and their limitations.

Academic interest in the field of SCRM has increased over time, and supply chains are more dynamic than ever before. Managers are increasingly aware of what can happen in a dynamic supply chain. Academic researchers have mostly focused on identifying, assessing, and mitigating risk. Blackhurst et al. (2008) confirmed this observation and mentioned that most supply risk-assessment investigations to date have focused on categorising and assessing risk or providing insights into mitigation risks.[86]

The academic papers reviewed in this chapter (Chapter 2) indicate that SCR management mainly involves four steps: (1) risk identification, (2) risk assessment, (3) risk mitigation, and (4) risk monitoring.[87] Academic literature shows also the importance of risk categories and risk classification in SCRM. Because risk categorising ensures knowledge of supply chain risks interdependencies and identify factors/triggers and their likelihood and consequences. Additionally, categorising risk allow a structured and systematic SCRM approach to assess risk severity and likelihood.

For example, SCRs can categorized in internal and external risk or in strategic, operational and environmental risk. This classification helps the analyst to select and tailor mitigation strategies likely to be most effective.[88]

The goal of this study to develop a risk management tool to ensure a structured and transparent risk management tool for company X. The main theory of this study is adapted from the work of Blackhurst et al. (2008); Thun and Hoenig (2011).

Finally, chapter 3 explains the methodology of this research, this chapters shows the problem solving approach and explains in-depth the data collecting methods of this research. For example, how the results are obtained, which methods are used, and how it used. The next chapters sections also discuss the results and models used to construct this risk management tool for company X. Chapter 5 explain in depth the approaches and applications of the SCRM phases in the risk management tool of company X.

[86]See Blackhurst et al. (2008, p. 146)
[87]Hallikas et al. (2004, p. 52).
[88]See Chopra and Sodhi (2004, p. 54)

3 Methodology

The aim of this research is to develop a SCRM tool for company X. Problem of company X is a typical business problem that needs to be solved. The theory of Aken et al. (2012) was applied during the research process.[89] This chapter defines the method used for collecting results. To provide an appropriate answer to the research question, it is important to align it with a methodology that suits the research goals. The aim of this research is to provide insight into SCR for company X and to create an SCRM tool intended to increase the efficiency and effectiveness of detecting SCRs, both in the current situation and the future. Development of a risk management tool would make it possible for the procurement department, which is responsible for a part of supply chain, to take action against certain risks when they are identified in the supply chain. Additionally, the department would be able to monitor risk in the supply chain using the multi-criteria scoring method.

The purpose of the study was determined by presenting the risks in a chart divided in external and internal risks based on Trkman and McCormack (2009) see Appendix III. For definition of internal and external risk, see section 2.6. Supply chain is a very broad term, and investigating all SCRs would not be possible in the time available for this research. Thus, this research focuses on the main SCRs faced by company X. Discussions with the managing director and purchasing director, they revealed that the main risks are both internal and external from purchasing perspective. Because, both are experienced in the SC field and are aware about the dynamic and hectic in the SC. Therefore, the student researcher addressed both types, focusing only on those critical supply chain risks. Critical risks are risks with high potential to disrupt the SC with high impact. Figure 3 presents the research output used in this study.

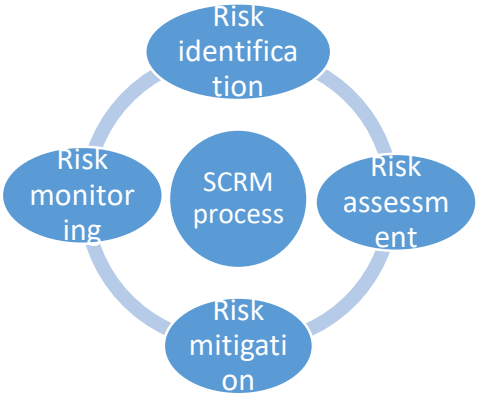

Fig. 3: Research output

Source: Hallikas et al. (2004);Hoffmann (2012) and Norrman and Jansson (2004)

[89] Aken et al. (2012, pp. 5-12)

3.1 Methodology of problems solving in organizations followed during the research project

As mentioned previously, the purpose of this research is to develop an SCRM tool for company X. The theory of Aken et al. (2012) focuses on improving performance based on designed solutions. The methodology is characterised as design-oriented and theory-informed. 'Theory-informed' means that problem solving is not carried out in a craftsman-like way but is instead largely reliant on academic experience in the field of SCRM.[90] 'Design-based' focuses on the design of a solution for a business problem.[91]

This chapter describes how findings in the academic literature are combined with data-collecting methods to ensure a tailored solution for the firm's business problem. As shown in Figure 3.1, the academic researcher used the problem-solving cycle for this research. This process ensures that that the problem-solving approach adopted in this paper satisfied academic requirements. Each step of the problem-solving cycle is discussed in the following sections of this chapter.

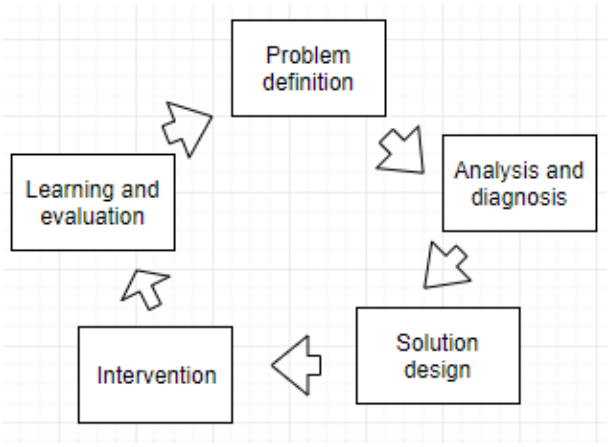

Fig. 3.1 The problem-solving cycle

Source: Aken et al. (2012, p. 12)

Step 1: Problem definition (Research proposal & chapter 1)

The first step in the problem-solving cycle is problem definition, in which a company's problem is identified and translated into a research proposal. The research proposal is constructed to formulate the problem.[92] The purpose of the research proposal is to define and

[90] Aken et al. (2012, p. 6)
[91] Aken et al. (2012, p. 6)
[92] See (Aken et al., 2012, p. 11)

clarify the business problem, and the research proposal is described per academic requirements and substantiated by academic literature.

Step 2: Analysis and diagnosis (Chapters 2 and 3)

After problem definition, analysing the problem to find possible solutions is the second step. This step consists of a literature review and construction of the methodology. Literature reviews in the field of SCRM are analysed to obtain a clear overview of the problem and the methodology of this research is determined based on appropriate methods.

Step 3: Solution design (Chapter 4)

This step consists of analysis of business documents, and in-depth interviews. This approach provides reliable information from respondents experience and business documents extra add reliable information from the practice. After the business problem is analysed, a solution can be developed. The solution design is developed based on interviews with experts from different disciplines, internal business documents, and assessment and monitoring approached of Blackhurst et al. (2008); Thun and Hoenig (2011). Input from the researcher's university supervisor and the company's purchasing director also provided ideas for the solution design. A detailed description of the structure of the SCR management tool can be found in Chapter 5.

Step 4: Intervention (Chapter 5)

The fourth step is the implementation of the solution at the company based on the actions identified in the design step.[93]

Step 5: Learning and evaluation

Evaluation is the final part of the problem-solving cycle. In this step, the effects of the problem solution are assessed and discussed. This step will involve evaluating the implemented tool to determine whether it actually provides support to the purchasing department in the decision-making process. The evaluation criteria are made by the purchasing department itself, and will complete this stage; the researcher will not be involved in this part of the cycle. However, the researcher presented the results and the risk management tool during the research process (see Section 4.3).

[93]See Aken et al. (2012, p. 12)

3.2 Data collection and sample

Data were collected through in-depth interviews conducted in the Netherlands with a sample of nine senior managers and professionals in purchasing, logistic, sales, engineering, and production from company X. The researcher chose a diverse range of respondents because the supply chain is about more than the logistics of purchasing (see Appendix X). The flow of the supply chain of company X is dependent on different disciplines of the firm, such as engineering, production, and sales quality, and on the second-tier suppliers.

The interview invitation was sent via e-mail to nine employees responsible for supply chain at company X. The e-mail contained information about the research, along with a question asking whether the respondents wished to participate in it. The respondents were free to participate in the research and to ask questions about its subject. A single e-mail to the respondents was sufficient to make appointments for the interviews, as they were both interested and quick to respond. In addition, due to the time constraints of the research process and the work pressure experienced by the respondents, the aim was to collect data as quickly as possible. The duration of each interview was approximately 0.5–1 h; interviews occasionally lasted 1.5 h, depending on the experience of the respondents and the degree to which they were integrated into the firm's SC.

In total, the interviews yielded nine usable responses, all selected respondents were invited and there was not unusable responses, because the respondents were carefully selected. (see Table 3.2). In consultation with both the researcher's university supervisor (the second reader) and professionals at the company, the respondents selected were (1) the product line director, (2) the operations leader, (3) the operations project manager, (4) the engineering director, (5) Indirect procurement manager, (6) the senior director of sales, (7) the manager of logistics, (8) the manufacturing engineering manager, and (9) the sales support manager. On average, the respondents have spent nine years at company X in different positions.

Function	Number of years' experience	Interview date
Product line director	1	11-02-2019
Operations leader	25	30-01-2019
Operations project manager	9	29-01-2019
Engineering director	12	05-02-2019

Indirect procurement manager	15	28-01-2019
Senior director sales	2	04-02-2019
Manager logistics	10	28-01-2019
Manufacturing engineering manager	4	04-02-2019
Sales support manager	4	06-02-2019

Table 3.2: Interview respondents

3.3 In-depth interviews based on Galletta's semi-structured method

A semi-structured approach featuring a list of specific questions was employed, with sufficient time being provided to obtain additional information and pose further questions. Additionally, the semi-structured method ensured that the researcher covered the correct material.[94]

In conducting the interviews, the researcher played a dual role: a content-oriented role, aimed at obtaining clear and unbiased answers to the research questions, and a management role, aimed at managing the interview process (e.g. managing the time spent).[95]

The structure of each interview featured an: opening, middle, and concluding segment (Galletta, 2013).[96] This allowed for a smooth process, as the participants were aware of the subject of the research, and could avoided unnecessary answers through by asking the right questions in a structure.[97] The opening segment of semi-structured interviews involves 'creating space for a narrative grounded in participant experience', the middle segment features 'questions of greater specificity', and the concluding segment involves 'revisiting the opening narrative for important theoretical connections and moving toward closure'.[98] The use of segments ensured a smooth progression from very open-ended questions to more specific and theory-based questions.[99]

In the beginning of each interview, the researcher introduced the problem-solving project and her background. Researcher also explained the goal of the interview and why the respondents were important to the research. According to Aken et al. (2012), it is necessary to mention the confidential nature of the interview process and leave room for some additional

[94]Bradley and Harrell (2009)
[95]Aken et al. (2012, p. 179)
[96]See Galletta (2013, pp. 46-51)
[97]See Aken et al. (2012, p. 179)
[98]See Galletta (2013, pp. 46-51)
[99]See Galletta (2013, p. 47)

questions about the research.[100]

The purpose of the opening segment was to create a level of comfort on the part of the respondents to allow them to feel free to speak; this was done with the aim of obtaining appropriate information. The first segment of the interview used sufficiently broad questions to quickly move the respondent to discussing her or his experience.[101] The interview questions from the middle segment were related to the research questions (see Chapter 1.3). These questions were more specific and theory-based, and the middle section involved considerations regarding the subject of the research. The aim of the middle-segment questions was to collect data of greater specificity and broader contextual levels (e.g. by asking questions about specific problems in the supply chain, SCR, supplier risk, mitigation actions, risk categories, and monitoring tools).

The final segment of the interviews offered an opportunity to summarise the preceding discussion. The respondents were also asked about any additional questions or final points that they may have wished to address concerning this research. Finally, there was space for providing feedback or discussing any misinterpretations concerning the interview process and/or the research topic. The respondents reported that they were satisfied with the interview process. A respondent concluded that discussing the subject SCR would promote awareness of this issue, which would ensure greater access to knowledge.

3.3.1 Recording, transcribing, and analysing the interviews

After interview data concerning the business problem faced by company X were collected, the information provided by the respondents was analysed. The interviews were recorded during the interview process and later transcribed. Each recorded interview was analysed, and important notes and quotes were included in the results. During the interview sessions, the respondents asked some questions that were not related to the subject (e.g. personal questions for the researcher); these kinds of discussions are not included in the results.

Oliver et al. (2005) mentioned two types of transcription, naturalism and denaturalism.[102] Naturalism involves describing every single word and utterance in detail, whereas denaturalism removes unnecessary elements of speeches[103] (e.g. examples, pauses and involuntary vocalisations).[104] The researcher used the denaturalist transcription method to avoid unnecessary elements in this research. Moreover, to promote easy reading, when the

[100]See Aken et al. (2012, p. 179)
[101]See Galletta (2013, p. 49)
[102]Oliver et al. (2005, p. 1273)
[103]See Oliver et al. (2005, p. 1273)
[104]See Oliver et al. (2005, pp. 1273- 1274)

transcriptions were completed, the answers provided during the interviews were summarised and published in a framework (see Chapter 4). This framework is divided into three parts, namely the interview questions, identified critical risks (as bullet points), and a column with examples provided by the respondents. This framework provides a broad overview that is easy to understand and allows for quick analysis of the answers given by the respondents.

3.4 Business documentation provides reliable information about supply chain risks.

In many problem-solving projects, it is helpful to use existing documents as a source of information.[105] The researcher used the internal business documents as a secondary source of information. There is a chance that the respondents did not have the correct knowledge of the risk(s) in the supply chain. Another important advantage of consulting documentation is that it provides information that respondents may have partly or completely forgotten to mention during the interview sessions.[106] Moreover, business documentation provides additional reliable information beyond respondents' opinions,[107] as respondents speak from their experience, and their experiences may differ from those of others.

At the beginning of the research process, collecting information from business documentation was essential to better understanding the scope of the purchasing department. For example, reading about the procurement process and procurement policies was helpful in determining the scope of the purchasing department's responsibilities. Moreover, business documentation provide more detail and information concerning the supply chain and supplier performance. The performance scorecards and portfolio analysis reports from company X were used to obtain more information about the overall SCR data. The documents provide information about performance and quality criteria and the documents show an overview about practical results. Chapter 4 go deeper in detail about how it used what kind of data and the core of the documents. The supply risk data available were limited; therefore, the most recent and available data are included in this research.

A quality engineer at a supplier create the overall performance scorecard used when company X collaborates with suppliers and during supplier audits. The scorecard measures the quality, delivery, payment, and service performance of each supplier. The scorecard indicates the performance of a supplier using charts and thresholds.

Strategic purchasers, a purchase assistant, and the purchasing manager created the

[105] Aken et al. (2012, p. 180)
[106] See Aken et al. (2012, p. 180)
[107] See Aken et al. (2012, p. 180)

portfolio analysis report, which is more supplier- and commodity-specific. The report shows the risk of a specific commodity (e.g. the scarcity of the material, overall improvement on the part of the supplier, and distance). This approach to measuring supplier risk involves some risk related to the experience of a purchaser with a specific commodity. Finally, the business documentation that could be used for this research was very limited, as company, X does not have specific documentation concerning SCR.

3.5 Validity and reliability

Research validity stands for: measuring right information that need to be measured.[108] To ensure the validity of the research, first academic literature is analysed to understand the concept of SCR. Then in consultation with the purchasing director interview were construct with fixed questions and a fixed structure. The interview questions were constructed to identify SCR and were for all nine respondents in the same structure, and only respondents were invited that are directly connected with the SC of company X. The interview questions used during the research interview process can be found in Appendix II. However, before the interviews were conducted, to ensure the reliability and validity of the interviews, the questionnaires were tested with purchasers from an external company in the Netherlands to ensure the clarity of the interview questions and to test whether the questions answered the research question. This advice comes from the first supervisor to ensure validity and reliability of this research.

The researcher chose the in-depth interview method for a number of reasons. The main reason is that interview research provides qualitative information and identified SCRs through the questioning of respondents about their experiences regarding SCR. The method is also appropriate for helping to understand the research problem through posing in-depth questions.[109] Interviewing was also considered an appropriate method for consulting the firm's most experienced employees about SCRs due to the ability to ask detailed questions concerning SCR topic.

The respondents who are directly connected with the supply chain of company X were chosen. Thus, to ensure the reliability of the results, receptionists, cleaners, or production employees were not invited to participate in the interview process.

Reliability concerns the trustworthiness of research results, and results are more reliable when they are independent of the researcher. [110] Regarding the reliability of this

[108]See Bryman and Bell (2011, p. 42) and see also Winter (2000, p. 4)
[109]See Golafshani (2003, p. 604) and see Miles and Gilbert (2005, p. 12)
[110]See See Aken et al. (2012, pp. 204-205) and see also Winter (2000, pp. 4-5)

research, the respondents were invited and asked to answer the interview questions that was constructed for this research according to (Galletta, 2013) interview structure. This structure of the interview ensures comfort for the respondents, so that the respondents feel free to answer the interview questions see section 3.4. Furthermore, when the research is replicated in other studies with the same conditions, the answers could be the same. Because, the selected respondents were directly asked to share their experiences regarding to the critical supply chain risk of company X, all questions were the same for each invited respondent and business documentation were used as second source to collect data.

On the other hand, there is also a chance that the results could vary when the research is replicated. For example, the respondents have the freedom to indicate different SCR scenarios. As last, this research focus only on the critical SCR and the questions are constructed to identify main SCR from respondent's experiences. For example, in the middle segment of the interview questions the respondent were asked to share experience about most critical SCR and the effects.

3.6 Conclusion of the methodology chapter

This section provides an overall conclusion to the methodology chapter. During the research process, the problem-solving cycle of Aken et al. (2012) was followed. This cycle ensures the formulation/development/implementation of a structural business problem-solving method.

After defining the problem faced by company X, the research question and sub-questions were formulated, this was followed by a literature review that analysed the problem (see Chapter 2). After analysing the problem, interviews were conducted with employees from different departments. The aim of the interviews was to obtain in-depth information about the SCRs, risk categories and examples of supply chain problems from the respondents' experiences. During these interview sessions, the researcher collected usable information from respondents. Results from business documents were also consulted to help answer the research questions. Because the research question could not be answered using only interview results, the overall performance scorecards and supplier portfolio reports were also analysed for this research.

Chapter 4 explains in more detail the findings of the respondents and the data obtained from business documentations based on critical SCR. The critical SCR and the experience of selected respondents are shown in this chapter.

4 Empirical findings: Findings based on interviews and business documentation.

This chapter discusses the results obtained from the interviews and business documents. It is necessary to know the SCR before developing a SCRM tool. In this research, identifying what SCR risk are exist and what risks are potentials was necessary. Because, identifying risk create comprehensive understanding of the risk and this leads to better process results. After identifying, risk level indication was possible and further the purchaser were able to develop tailored mitigation strategies to counteract the SCRs. In addition, it provides an overview for the stakeholders and for the company, measuring risk level gives insight, and company X has time to react in the future. Additionally, SCR identification is necessary for the next steps in the SCRM, because this step clarifies the origin of the risks and ensures that the right mitigation strategies are used by the purchasers to counteract/avoid these risks. Appendix XII show the empirical findings and is divided into three sections: The first column identifies the respondent, the second highlights the critical SCRs identified, and the last column summarises the findings, using examples from the respondents regarding their experiences. The aim of the interviews was identify as many of the risks in the supply chain and risk categories as possible, with this information to be used in the development of the risk management tool. Table 4 below lists the most critical SCRs, which will be included in the risk management tool. The other results from the data sampling process are presented in Sections 4.1, 4.2, and 4.3. At last, publication of the supplier's names is not possible in this study, so the researcher developed tables in this section that presents the results of the critical suppliers of company X see therefore table 4.2.1.

Supply chain risk

Table 4 Identified risk

SCR	Definitions	Critical because	Disruption probability
Quality performance	Numerical measurements of supplier quality performance	• Directly related to the component	High
Delivery performance	Numerical measurements of transportation performance	• Directly related to the component and delivery performance	Medium
Specific automotive requirements	Requirements that must meet in the automotive industry, for example, ISO	• Influences the direction of supply chain flow	High

	certificate is necessary or intellectual property.		
Design of components	Component/ product architecture	• Directly related to components	High
Sourcing complexity	Difficulties to source materials and supply	• Limited alternative sourcing	High
High dependency in the automotive industry	High dependent on suppliers capacity, delivered goods and collaboration	• Company X is dependent on both supplier and OEM	High
Supplier risk	High probability that supplier fall to deliver components or disrupt the SC of company X	• Dependency on suppliers is high	High
Environmental risk	Uncontrollable risk. Risk outside the company for example, flood or terror attack	• Most of the supplier are based abroad	High

4.1 Input from professionals relating to identified critical supply chain risk of company X

The results of the interviews indicate that company X is confronted with many SCRs, internal as well as external risk, while the definition of SCR in the previous chapters indicate that the SCR of company X exist mainly in the upstream level of the SC. The results also provide insight into the SCRs found in the industry in which company X operates. As several employees mentioned, 'dependency, automotive requirements, and quality' are the most important critical risks in the current situation and have high potential to disrupt the supply chain. The risks mainly exist upstream, but there also internal issues that can lead to temporary disruptions such as miss communication with both sides of the SC. As discussed with different respondents in the supply chain, Company X is mainly dependent on other parties but must also abide by the strict requirements of the automotive industry. The company operates as an intermediary between suppliers and OEMs. Company X buys materials from suppliers, assembles them in its factory, and sells products to the OEM. According to one respondent, it is sometimes difficult to ensure that business flows smoothly in a dynamic supply chain. The consequences of this type risks for the company X and their supply chain from is high. Disruptions to the supply chain are partly created by suppliers'

delivered materials, product quality, or operational issues. It is notable that other risks sources also had effect on the performance of company X, such as Brexit-related problems or the decision to relocate the plant to Turkey.

An example of one of the disadvantages of operating in the automotive industry is, for example, when product quality does not meet the industry's strict requirements, all received goods must be returned and the product re-released. The consequences are delays in material, assembly thereof, and delivering goods to the OEM. As a result, company X experiences a temporary pause in production, as does the OEM.

Another frequently mentioned issue is that non-BOM materials are not included in the bill of materials, but these products are needed to assemble or clean components. The respondents indicated that a high level of knowledge of these products is necessary to use them correctly, and to thus achieve a sufficient level of quality.

4.2 Results of the analyses of the business documents, scorecards, and supplier portfolios

4.2.1 Scorecard results

As mentioned in Section 3.5, business documentation can provide extra reliable information when compared to interviews (Aken et al. (2012). Therefore, business documentation is used as a secondary data source in this research. These data provide additional information for the risk management tool. The results from both parts of the research are incorporated into the tool. The tool used the risk aspects like delivery, quality, design and specific requirements from the business documents as risk categories so that the analyst can focus and monitor the main risk in the tool. In addition, these tables provide transparency/overview about main SCR for company X and their stakeholders. The first set of data that the researcher found measures suppliers' overall performance in terms of, quality and service. The second dataset measures the SCR associated with a particular supplier's performance in terms of delivering a specific commodity

After the interview process, the results obtained by analysing relevant business documents were compared with the answers provided by the specialists. Figure 4.2.1 summarises the results that was found in the business document titled 'scorecard'. Table 4.2.1 presents the results using the letters A to D. An A means 'good performance', while a D means 'bad performance'. From Table 4.2.1, the reader can determine the performance of each individual supplier in various areas.

Performance risk						
Score card results	Supplier 1	Supplier 2	Supplier 3	Supplier 4	Supplier 5	Supplier 6
Quality performance	C	A	A	A	B	A
Delivery Performance	D	D	A	B	B	B

Table 4.2.1: Overall performance results

The results in Figure 4.2.1 indicate the overall performance of company X's six critical suppliers. Critical supplier for this research are selected on basis of low performance. Suppliers above have the lowest performance on some aspects with potential to disrupt the SC. Company X experience also some disruptions from these suppliers above. Table 4.2.1 summarises the overall performance of these six different suppliers. The results above indicate that suppliers 1 and 2 demonstrate low delivery performance compared to suppliers 3, 4, 5, and 6. Quality performance and delivery performance are generally low for some specific suppliers. Moreover, the results presented in Figure 4.2.1 partly confirm the results of the interviews with regard to quality risk. A few respondents mentioned that quality is the main SCR, but they did not discuss delivery performance as an SCR. However, the overall results indicate low to medium delivery performance on the part of suppliers, which means a potential risk for company X. Finally, the information obtained from the scorecards was limited, as the researcher received only a single document from company X. Therefore, not all suppliers' performance could be analysed; only critical suppliers that have the potential to disrupt the supply chain are included.

4.2.2 Supplier portfolio data results

Supplier portfolio data is an Excel file where all data is kept about commodities, for example, data such as suppliers performance, supplier risk and quality aspects. The Excel file is divided in tabs, namely: spend cube, risk per article group, supplier analysis, suppliers perspective and strategies to mitigate supplier risk per commodity. This data are collected by strategic purchasers to monitor the commodity risk with the aim to do improvements in the next year, and there are 12 main commodity portfolio analysis available.

Therefore, supplier portfolio data results are collected for this research, these results indicates the supply risk per commodity. The supply risk score is based on different aspects, including design, specific requirements, intellectual property, number of potential suppliers,

alternative sourcing options, specification and verification, and the ‘gut feeling’ factor. The scores are defined by the purchasing department, mainly through strategic purchasers. The scores are based on estimations and previous experience with the specific suppliers. Figure 4.2.2 presents the 12 important commodities, including the supply risk score for each commodity. The original measurement model/file is not included in this research; therefore, the researcher has provided a self-developed table with the results from company X data (see Table 4.2.2).

Commodity risk												
	Hose assembly	Motor	small turning part	Bodies	Seals	Metal casting	TR Plunger	Hardware	Tubes	Bases	Stamped Parts	Large turning parts
Design	HR	MR	MR	HR	MR	HR	MR	MR	HR	HR	HR	MR
Specific requirements (Iso & TS16949)	HR	MR	MR	HR	MR	HR	MR	MR	HR	HR	MR	MR
Intellectual property	MR	HR	LR	LR	MR	LR	LR	HR	LR	LR	LR	LR
Number of potential suppliers	LR	LR	LR	MR	MR	LR	MR	LR	HR	LR	LR	LR
Alternative sourcing	MR	HR	LR	MR	MR	HR	MR	LR	MR	LR	MR	LR
Specification and verification	HR	HR	MR	HR	MR	HR	MR	MR	HR	MR	HR	MR
Supply risk total score	7,4	6,6	2,8	7,2	5	6,6	4,4	4	6,8	4	6	2,8

Table 4.2.2: Supplier portfolio data results

Table 4.2.2 indicates the risk aspects as follows: ‘HR’ for high risk, ‘MR’ for medium risk and ‘LR’ for low risk. Additionally, Figure 4.2.2 indicates the total supply risk for each specific commodity. These numbers are measured in the ‘portfolio analyses by ranking each aspect as high, medium or low supply risk through strategic purchasers. Risk scores between zero and four are low risk, those between four and six are medium risk, and 6 to 10 indicate high risk. The thresholds of supplier portfolio data is determined by a strategic supplier and how the thresholds are define is still unknown. The supply risk total score is automatically calculated using an Excel formula. The calculations include two variables, namely a ‘supply risk score’ (low, medium, high) and ‘aspect weight’. Every single aspect is evaluated by purchasers during meetings, and the results are based on experiences and probability. The formula of the SR results are based on weights and ratings from zero to 10, where zero represents low risk and 10 high. For example, the following equation is used to calculate the value for hose assemblies: 15% * 9 + 15% *9 + 15% * 5 + 15%*9 + 25% * 5 + 0% * 0 + 15% * 9 + 0 = 7.4. Scores, indicate supply risk per commodity and suppliers. The scores cannot specific compare with each other, because each commodity is different and the suppliers are not the same. Actually, every single commodity data is separate presented in the company in an Excel file, but in this research the student researcher summarize the commodities in a table for an transparent overview for the reader. Furthermore, some aspects have a rating of zero because there is no information available concerning them or because they not applicable to

the commodity in question. In addition, the numbers are shown in the Excel file and publication in this research is not possible.

Table 4.2.2 shows medium to high risk, consistent with what the selected respondents discussed during the risk-identification interviews. According to the data obtained from the business documentation, risks are generally associated with commodities and the corresponding suppliers. The risks exist mainly in the design, specific requirements, alternative sourcing, and specification and verification aspects. Additionally, the risk scores of suppliers are high for some commodity groups. For example, hose assemblies, motors, bodies, metal casting, tubes, and stamped parts are risky, as these components are important for the end product and are not routine items.[111]. Chapter 5 goes into more detail concerning the risk management tool, including its use and sensitivity.

4.3 A presentation delivered to specialists led to evaluation of identified supply chain risks and the risk management tool

After data were collected from the literature and interviews, the goal was to present the results concerning the identified SCRs. The group invited for the presentation was satisfied with and positive about both the results and the risk management process. In particular, the assessment and monitoring aspects are relevant for company X, as, prior to this research, the company did not have any tool or process for measuring SCR. The risk assessment tool presents the risk scores visually, the scores are measured by the probability- impact matrix and multi-criteria scorings procedure. See next chapter for the risk score calculation. Most of the group members were satisfied with the results and indicated that the visual representation of the risk scores was easy to read. The risk scores are colour-coded as red, orange, yellow, and green. Each colour has its own significance and indicates the risk level per identified risk.[112] Chapter 5 elaborates on the thresholds, percentages, colours, and use of the tool.

The results regarding SCR differed from the group's expectations. The members of the group were interested particularly in results that identified risks in the operational and strategic areas. They did not expect that most of the SC risks would be internal, although the survey respondents mentioned that risks partly exist internally during the interviews.

Another positive evaluation concerned environmental risk assessment. Most of company X's suppliers are located in Germany, China, France, the UK, and the USA (see Appendix VII. The group members agreed that measuring environmental risk to supply chain performance is relevant. They were satisfied with the fact that measuring risk will help the

[111]See Kraljic (1983, p. 112)
[112]See Norrman and Jansson (2004, p. 449)

company's specialists make better decisions regarding the supply chain. Assessing risk in the environment is a strategic advantage for company X, mainly in terms of selecting a strategic supplier, because early preventing of environmental risk or risk areas would be an advantage for company X. That is also the aim of the risk management tool.

In addition, the risk management tool was presented to the group during the presentation. The architecture of the risk management tool was based on Excel file which, based on the studies of (Hallikas et al., 2004; Hoffmann, 2012; Norrman & Jansson, 2004), and is divided into four phases: risk identification, assessment, mitigation, and monitoring. The goal behind the risk management tool is that a purchasing specialist can measure risk using a process-based method to assess risk and mitigate it with the described mitigation strategies, and then continuously monitor it with the aim of avoiding or decreasing the likelihood of a risky situation in the future.

4.4 Conclusion: company X's challenges lie mainly in dependency, automotive requirements, and quality commodity risk in the supply chain

Based on the results of the interviews and business documentation, a clear overview of the risks faced by company X was created. The results provide new insight into the supply chain for the respondents. The respondents were more aware of both current and potential SCRs. In addition, after the presentation, the respondents were more aware of the effect of risk management on performance (see Section 4.3).

The interview method provided information drawn from respondents' experiences with which to identify risks in the supply chain. For confirmation, a few business documents were used as secondary data in this research. As mentioned earlier in section 4.2.2. the interview results were mostly consistent with the business documentation. This ensures the reliability of the research results.

The most common risks involved dependency on suppliers, the requirements of the automotive industry, quality, and commodity risk. Another interesting result was delivery performance; this aspect was not mentioned during the interview process, while the scorecard result indicates that transport performance is medium to low. The risk management tool developed for company X provides a broader overview of SCRs, with main SCRs being incorporated and non-critical SCRs being omitted. For example, quality, manufacturing, supplier dependence, procurement and environmental risk aspects are incorporated in the risk management tool. These aspects were discussed during the interview sessions and determined by the business documents and incorporated in the tool.

The risk management tool was presented to the other group members that is

responsible for the supply chain. During the presentation, the process of creating and the use of the risk management tool were explained. The group had questions, comments, and feedback about improving the tool. They had for example questions about the colours and meanings of the colours, therefore changes such as adding a legend was useful in the tool. Further, there was no other changes needed, because the construction/architecture of the tool was in the begin phase internally discussed whit the purchasing director.

The presentation was necessary for other purchasers. The researcher had the opportunity to explain the methodology, results, recommendations, and conclusions, and the group had the opportunity to ask questions about the risk management tool. The group was ultimately satisfied with and positive about the research results. They were also satisfied with the architecture and visual construction of the risk management tool.

The next chapter explains in detail how the risk management tool was developed and how it functions. Moreover, the following topics are covered: threshold of risk levels, scores and percentages, meaning of colours, adjustments to the tool, sensitivity of the tool, and, finally, a brief process description.

5 Research model: risk model developed to assess the level of supply chain risk based on empirical findings and scientific theory

This chapter discuss the construction of the risk management tool in detail. Each section discuss the highlights of the tool for example, this chapter go deeper in assessment and monitoring methodology and calculations. Besides that, Appendix V shows also the entire process systematically in a chronological order.

5.1 Construction of the risk management tool

The results from interviews and business documentations are collected and shown in chapter 4. Based on the academic literature and discussion with the specialists, the researcher constructed a risk management tool based on the 'probability–business impact model' and 'multi-criteria scoring method'.[113] Both models are used in the automotive industry to assess and monitor risks in the supply chain with positive results. In addition, both models are easy to use, assess and monitor SCR, and are easy to understand using the partial heat graph method to represent the results.[114]

According to the results, the identified SC risks are 'commodity risk' and 'overall performance risk', which include the following risk aspects: 'quality performance, delivery performance, automotive requirements, design of components, sourcing complexity, supply risk, environmental risk, high dependency in the automotive industry'. The SCRs are divided into classification and categories. First, risk identification shows the relevant risk for company X. Second, risk assessment phase indicates the level of risk with colours and the scores are based on (Norrman & Jansson, 2004) approach. Third, risk mitigation shows tailored mitigation strategies. Fourth, risk monitoring phase monitor risk categories quarterly. See Appendix VI for a visualize risk management tool.

5.1.1 Application of probability and impact matrix in the risk management tool ensures to assess the critical supply chain risk

The outcome of the previous step ensures an overview of critical SCR for the analyst. As discussed earlier, one of the outcomes of this research was to be able to assess risk in the supply chain. Therefore, the assessment methods of (Mitchell, 1995; Norrman & Jansson, 2004; Thun & Hoenig, 2011) are used for assessing the SC risk for company X. The level of risk can be measured by multiplying the probability of risk by the business impact based on the Likert scale. The Likert-scale scores indicate the risk level and describe the value of the risk (Norrman & Jansson, 2004; Thun & Hoenig, 2011). As discussed earlier for measuring

[113]Blackhurst et al. (2008); and see Thun and Hoenig (2011, p. 244)
[114]See Blackhurst et al. (2008, p. 153)

the risk level, Likert-scale scores range from zero to five, wherein a higher score refers to high risk in the supply chain and a lower score refers to low risk. The risk scores can be based on a risk's likelihood and occurrence to disrupt the supply chain. Moreover, the specialist must assess both the probability and the business impact with scores from zero to five. Each identified risk in the supply chain must be assessed individually for a clear and transparent risk score. The risk score will help direct the specialist to what the next step in the process regarding to counteract the identified risk. The total score shows red, orange, yellow and green colour, each corresponding to a risk degree and risk level. Risk degree indicate risk in words, for example high, medium low and risk degree shows the risk in colours for example red, orange, yellow and green. Red refers to high risk and green refers to low/minimum risk. The thresholds are based on theory of (Norrman & Jansson, 2004; Thun & Hoenig, 2011).[115] The colour results ensure that the specialist knows which identified risks need a mitigation strategy for improvement and that it is easy to understand the degree of the overall risk.

5.1.2 Mitigation strategies are based on interview results and the academic literature

The mitigation strategies described are partly based on the academic literature and interview results. The reason for using two sources for this approach is that during the interview process, respondents provided some practical and logical solutions to solving the current SC risks according to identified risk, and using robust strategies for SCR mitigation from different researchers could be effective for improving supply chain performance. These results are incorporated into the risk management tool and divided into three sections, mitigation 1, mitigation 2, and mitigation 3. The reason for this approach is that the analyst (strategic purchaser) can use different mitigation strategies when one does not work. Additionally, the analyst can check which strategies are from the academic literature and which are from the interview results; blue and yellow distinguish these.

Next, the specialist can add or change mitigation strategies in the Excel file by making use of "what if scenarios" of Chopra and Sodhi (2004) (see Appendix VIII), and if the strategies are tested by the matrix 'assessing the impact of mitigation strategies' of Chopra and Sodhi (2004)[116] (see appendix IX). Because of the sensitivity of the supply chain, the mitigation strategies have the potential to disrupt the supply chain, so the managers need to know which mitigation strategy work best against given risk.[117]

[115] See Norrman and Jansson (2004, p. 11); See Thun and Hoenig (2011, p. 244)
[116] See Chopra and Sodhi (2004, p. 55)
[117] See Chopra and Sodhi (2004, p. 55)

5.1.3 Multi-criteria scoring procedure could be used to analyse and monitor risk in the supply chain

For risk monitoring, the multi-criteria scoring procedure is used. To develop risk indices for commodity and supplier performance. The multi-criteria scoring procedure helps the purchasers with decision making in situations where a number of different risk factors must be assessed and monitor at the same time for example, company X. Number of different risk factor must be assessed for commodities at once.[118] For an extensive example of the methodology, consider the brake system and related components in the research of Blackhurst et al. (2008).[119] In this research, the risk-monitoring methodology is based on the tracking of commodity risk and supplier risk performance, so that company X can monitor risks and compare these results with the negative and positive performances of each individual supplier. According to the interviews and business documentation results, company X is challenged mainly with commodity risk and operational risk. These risks are mentioned as 'main risks in the supply chain'; see Chapter 4. The monitoring system based on the methodology of Blackhurst et al. (2008) ensures transparency and overview about risks, so that decision making about different risk factors is easier. Other advantages are that the methodology shows the results visually as colours and comparing each individual supplier performance per commodity is be possible. The next sections will the construction of this methodology more in depth. See Appendix VI for a visual overview of the risk management tool.

5.1.3.1 Categories of risk

First, the risk categories must be specified to monitor risk in the supply chain. As discussed in various chapters, the categories included in this methodology are based on interview results, business documentations, and partly on the academic literature see table 2.6 and chapter 4 for the risk categories and main risks.

Each risk category is further divided into subcategories. The incorporated subcategories in the risk management tool are based on business documentations and (Blackhurst et al., 2008) risk categories. Appendix XIII shows the tailored risk categories based on the needs of company X. These subcategories more deeply explain the origin of that specific risk category, which ensures that the analyst knows where the risk comes from and what causes of a high degree of risk. For example, quality is the first risk category for company X in the current situation. The quality category is dependent on other variables such as defects/rejected ppm (parts per million), ease of problem solution, timeliness of corrective

[118]See Blackhurst et al. (2008, p. 147)
[119]See Blackhurst et al. (2008, p. 147)

actions/response, and repeated defect rate, which are the subcategories connected with the quality risk category. The subcategories are defined by business documentations and some are based on Blackhurst et al. (2008) sub categories. For example, the sub categories of "quality aspect" are based on "score card results". Supplier engineers determine the quality performance of a supplier by giving points on these sub categories. Other example is, supplier dependence and procurement risk categories, some subcategories of this aspects are based on Blackhurst et al. (2008) theory, because this sub categories fits the best with the risk of company X. When one of the subcategories has low performance, the overall quality performance will decrease, which results in high risk in the risk management tool. The challenge for the company is then working on that part to improve the quality risk issues. When the subcategories for each risk category are unknown, finding a solution would be a challenge, so a clear overview of the categories is necessary.

Finally, the risk categories described in Appendix VIII are specifically geared to company X and incorporated in the risk management tool. Because, after analysing results the student researcher discovered other risk categories from business documentation that fits with company requirements and needs. It should be noted that other firms adopting this methodology will need to define risk categories determined by their own needs, industry, and supply chain type. Blackhurst et al. (2008) mentioned that there is no 'one size fits all' approach to assessing risk.[120]

5.1.3.2 Data requirements

The multi-criteria scoring procedure uses weights to indicate how important each risk category is with respect to disruptions in the supply chain. The weights in this research can be based on the probability of disruption and occurrence for each category, for example, the relative impact that each category of disruption has on the supply chain.

The sum of all category weights in this methodology must equal 100%. For example, for company X, quality could be more important than manufacturing risk. Thus, quality could be higher in percentage than manufacturing risk. This process is necessary for each risk category in the tool in consultation with other specialists at company X. Because the weights shows the urgency of each risk category, an alternative is that the weights can also be determined by the subcategories, such as the likelihood to disrupt the SC.

When all relevant risk categories/subcategories are defined, a rating must be established for the performance of each supplier on each subcategory. Separate ratings must

[120]See Blackhurst et al. (2008, p. 148)

be entered for each individual supplier.[121] For example, in the case of the quality category, each subcategory must be assessed by rating 0–100 for each individual supplier for that specific commodity. This ensures an overview regarding the performance of each risk category/subcategory based on specific commodity and supplies per supplier.

The rating for each individual subcategory based on a scale from zero to 100; a higher number indicates the supplier's performance is worse on that subcategory.[122] For example, a rating of 70 for supplier 1 in 'defects/rejected ppm' indicates that supplier 1 has a poor performance in that subcategory. In contrast, supplier 2 can have a rating of 20 for 'defects/rejected ppm', which indicates good performance. The thresholds are based on the theory of (Blackhurst et al., 2008) and indicate the percentage of each risk category.[123] Next section 5.1.3.3 go deeper in subcategory thresholds. Comparing supplier performance in each individual subcategory makes it to track improvements in supplier performance as well.

Next, the data from business documentation could be applicable for weighting risk categories. Because, the risk categories are determined and based on these documents, mainly the quality risk category aspect. The specialist can open the document 'scorecard', for example, to analyse the scores for the quality criteria. This is also applicable for other subcategories in this methodology, such as transport or labour availability. The analyst can analyse the data and in consultation with other responsible employees determine a probability indication for these risk categories.

Overall, an estimation can be made from these results and entered in the monitoring system per quartile such as other estimations of risk categories. In the case of disruption/disasters such as earthquakes, flooding, and terrorism, decisions can based on hard data for example, internet source or experience. In general, strategic purchasers know how frequently this type of accident occurs in a country and can estimate the probability of occurrence for new and current suppliers.

5.1.3.3 Risk assessment calculations

When the previous steps are completed and all risk categories are filled in on basis of rating and weights, the total risk score will be automatically calculated in the Excel field. However, an extensive explanation about the calculations is necessary in this research. In this monitoring system/framework, the multi-criteria scoring procedure is used to calculate multiple risk categories at the same time in the Excel field (Blackhurst et al., 2008).

[121]See Blackhurst et al. (2008, p. 150)
[122]See Blackhurst et al. (2008, p. 150)
[123]See Blackhurst et al. (2008, pp. 150 -153)

For each part, the risk-assessment score for each subcategory is calculated by multiplying the supplier risk rating by the supplier rating on that subcategory, to get individual supplier scores on that subcategory. For an overall score for each subcategory, scores are summed up to get the overall risk score at the end with a formula. For example, (50*40) + (90*30) + (90*30) = 74, see Table 5.1.3. The overall risk score per subcategory will be automatically calculated though the Excel field. The overall supplier category rating for each subcategory found by multiplying the subcategory weight by the supplier rating of each subcategory, to get an overall result per category and per supplier. For example, (50*20) + (30*20) + (60*30) + (50*30) = 49. The Excel file calculate automatically the overall score. In this example (Table 5.1.3), supplier 1 and supplier 3 have medium performance in contrast to supplier 2. Thus, the analyst can take actions with the results to compare the activities with this supplier in the same commodity level.

The scores will range from zero to 100, with a higher score indicating a worse overall performance for specific subcategory. As mentioned earlier, to analyse quickly and easily the scores, the researcher included colours with thresholds in the monitoring methodology. The concept is similar to the concept of (Blackhurst et al., 2008; Norrman & Jansson, 2004). The colours that is used in the tool to highlight the severity of a subcategory for a specific commodity.[124] For example, in the monitoring phase, a critical risk score is greater than 75 and is shown in red; high risk is greater than 50 and less than or equal to 75 and shown in orange; medium risk score is greater than 25 and less than or equal to 50 shown in yellow, and lastly a low risk is less than or equal to 25 and is shown in green. The scores/thresholds are necessary to monitor risk in the further, because the thresholds shows the urgency of risk categories. These thresholds determined the risk per supplier of individual commodity. Other industries that use the methodology can also use the four thresholds based on Norrman and Jansson (2004) ratings, including critical risk, high risk, medium risk, and low risk based on scores of 0 to 100. Finally, appendix V shows the SCRM tool process step by step.

Risk category	Sub category	Sub category weights	supplier rating	Supplier risk rating	Supplier 2 rating	Supplier 3 rating	Supplier 4 rating	Total score
Rating		100%		40%	30%	30%	0%	Supplier rating per sub category x supplierrating (heat graph)
Quality		50%						
	Defects/ rejected ppm	20%		50	90	90	0	74
	Ease of problem solution	20%		30	50	20	0	33
	Timeliness of corrective actions/responding	30%		60	40	60	0	54
	Repeated defect rate	30%		50	20	90	0	53
Overall supplier rating for each part				49	34	49	0	

Table 5.1.3 Sample calculation of subcategories

[124]Blackhurst et al. (2008); Norrman and Jansson (2004)

5.2 Operational issues

This chapter discuss few operational issues regarding the risk management tool constructed for company X and this research paper.

First, when firms adapt the risk management tool, they should carefully identify and assess the risk categories and the subcategories focused on their own industry. Assessing the most important risks in the industry is necessary in this methodology.

Second, another issue in this risk tool was the sensitivity of the monitoring methodology. The methodology cannot handle large and complex supply chains with potentially more than hundreds of suppliers with more than thousands of parts. As a solution, advice was to focus on suppliers with critical performance and those that have the potential to disrupt the supply chain. For instance, the top four critical suppliers with poor performance on an individual commodity, so that the company can focus on the most critical supplier with the worst performance. The monitoring graph shows the risk in colours and illustrates the level of risk, but the monitoring methodology does not automatically update the data from the risk scores. The analysts will have to update the data in the tool themselves.

Third, the scores and weights in the risk management tool need to be assessed for each individual risk, risk category, and risk subcategory. The weights and ratings indicate how important each risk is regarding disruptions affecting the supply chain and company performance. In the case of monitoring methodology, a high weight on a risk subcategory will cause that the risk category to have more impact on the calculated risk. This also applies to the probability–business impact matrix; a higher score on a particular risk will have more impact on the calculated total risk score. As mentioned earlier, a few of the weights and scores can be determined by probability of occurrence and some risk categories are based on the business documentation.

Fourth, determining the environmental risks such as earthquakes, flooding, and terrorism is quite objective.[125] Collecting reliable information about these risks is necessary, specialists and managers familiar with this area of risk should determine these ratings.

Fifth, the risk scores are based on experience of purchasers, probability of risk and businessdocuments. The scores from the purchasers are more sensitive than scores from business documents. Because, the documents are practical measurements (facts) and risk estimations are based on probability and interpretations. Wrong interpretation of purchasers

[125]Blackhurst et al. (2008, p. 159)

cause wrong steps and wrong actions. Therefore, specialists and managers familiar with this area of risk should determine these weights.

Sixth, it is possible to change the weights of particular categories or sub categories. This makes it easy to analyse and investigate different what-if risk scenarios and the effect of each scenario based on the riskiness of a supplier. It is also possible to change the name of risk categories and the sub categories. However, the analyst must be alert when including new and excluding risk categories in the risk management tool (Excel file), because the risk management tool that is constructed in an Excel file and the weights and scores are connected through formulas. In particular, when a subcategory is incorrectly excluded or included in the risk-monitoring methodology, the calculation will change and the results will not indicate the true values. Thereby, the specialist working with the risk management tool must work accurately and know the calculation of the methodology. Further, if the specialist knows the calculation, including or excluding categories could be possible in the tool, but not frequently because of the chance of corrupting the formulas. It is not recommended that every specialist or specialists with less knowledge about formulas and the risk management use this risk management tool. In contrast, it is recommended that specialists who are familiar with SC risks, Excel formulas, and the supply chain to the risk management tool. It is notable that the risk management tool is sensitive to changes.

Finally, the Excel file is not connected to an ERP system, so the responsible specialist must manually update the data or other risk-related items. If the methodology is updated too frequently, it is difficult to get an overview and frequent use of the methodology will decrease. On the other hand, updating too infrequently ensures a reduced predictive capability of the methodology. Finally, this methodology should be used in a proactive manner. The risk tool should be used quarterly, and the data must be analysed for high/critical risk levels or trends that indicate problems for company X.

5.3 Conclusion: risk management tool assess and monitor supply chain risk and shows the risk level of a particular risk

The architecture of this risk management tool ensures transparency and it helps managers by decision making in situations where a number of different factors must be considered, mainly in the automotive industry.

The methods are easy to follow, apply and to understand. The proposed methodology calculates the risk level of each identified risk and monitor risks. The results are used to analyse main risk such as quality, manufacturing, supplier procurement and environmental

risk. This information can be used by the company proactively to handle SCR disruptions before they occur.

Feedback from different group member during the presentation (see chapter 4.3) was positive about the visual presentation of the risk sources. They were satisfied with the results, methodology and risk approach in the risk management tool. The visual approach highlight the severity of each risk with colours, this type of approach allow the analyst to focus quickly on critical risk or high scores in the tool.[126]

The supply chain of company X is dynamic and a structural use a risk management tool is therefore essential to avoid of minimise the likelihood of SC risk in the future.

Next chapters discuss the conclusion, discussion and further research, limitations of this study. The researcher is judicial about her own work and the limitations of this research.

[126]See Blackhurst et al. (2008, p. 153); Norrman and Jansson (2004, p. 449)

6 Implementation Plan

This chapter describes the process of construction of risk management tool. For detailed process description, (see Appendix V). Before constructing a tool, it is necessary to determine what steps and models are import for the tool. Therefore, chapter 2 describes and investigate the existing SCRM theory. It is also important to be familiar with the SCRM process.

6.1 Construction of the SCRM tool

This research implement the SCRM in a excel file, because Excel file is easy to use, many stakeholders are familiar with the process, Excel is transparent, Excel can provide a platform for creativity and company X monitored performance results in Excel files. So transferring information/data from one Excel file to other Excel file is efficient.

The SCRM phases are built in tabs, namely identification, risk assessment, risk mitigation and risk monitoring. Further, chapter 5 discuss in detail the calculation of each model, see therefore previous chapter. Table below discuss the important who, what, where, why, when how, how often and file save questions about the tool.

Who	The risk management tool is developed especially for the purchasing department, thus for the strategic purchasers of company X. However, the tool is so developed that other departments in the company can benefit from this tool. This is possible, if other departments identify risks in the identification phase according to their own segment in the industry. The inside of the tool is built up in tables and each table is a part of the tool, so the purchaser/employee must be accurate when changing data/formula or when adding extra information.
What	The tool is a risk tool that helps the purchaser to assess and monitor SCRs. The risk management tool is based on colour visualisation and shows the risk level of each identified risk, and monitor the high impacted risks after mitigation phase.
Where	The risk management tool is constructed in an Excel file and can be fined in the purchasing folder.
Why	Assessing and monitoring risk with the tool ensures transparency and overview. This approach ensures also structure in the company regarding to risk management. In addition, the implementation of the SCRM

	tool could have a positive effect on the entire company, as this SCRMP can lead to improvements and help it to better cope with unexpected developments in the SC.[127]
When	To avoid disruptions and minimise risk affects in the SC, advice is; frequent use of the tool. For company X means this per quarter, because the purchasers hold per quarter a meeting with all strategic purchasers to discuss the progress in the SC. This time is a chance to use the tool and discuss the outcome, improvements and declines of SCRs. This process ensures also thinking further from purchasing perspective to improve the SC performance.
How	The tool is built in that way that each purchaser can use and handle with the tool that is familiar with Excel. Additionally, to avoid errors in the file, the SCRM tool process is detailed described by steps (see Appendix V for the process). Advice: read the process before practicing the tool. This SCRM process description is also effective for knowledge and navigate the new/current purchasers through the process.
How often	This assessment should be done periodically, mainly when the SC is highly dynamic.
File save	Do not save results in the original file. Because the probability of disruption the formulas is high. Therefore, in practice save always the file with **"opslaan als or save as"** to prevent disruptions and so that the original file remains unchanged. Otherwise, go to chapter 5, read the calculation accurately and built according to these calculation the formulas again per tab in the Excel file.

Table 6.1 Tool instructions

[127] See Wieland and Wallenburg (2012, p. 899)

7 Conclusion and further research

The goal of this study was to discover the supply chain risks with the aim assessing and monitoring SC risk for company X. This research identifies several supply chain risks as important for company X and procurement professionals to be able to firstly avoid and minimize the impact potential SC risks, secondly to shift from a reactive to a proactive approach to using the SC risk management approach and thirdly to improve company performance and supply chain performance in the further. In contrast to previous supply chain risk studies and approaches, this research focuses on identifying supply chain risk with the aim constructing a risk management tool that can assess and monitor SCRs based on company X's requirements and results.

The business problem addressed in this research was that company X did not have a risk management model or a structure in place with which to assess or monitor risks in its supply chain. This paper presented the design of a proposed SCR assessment tool and included a monitoring methodology for the automotive industry in the Netherlands. The research goal was translate into a set of research questions that have been answered during this research process:

1.1 What are the SCRs for company X?

Based on interview discussions with respondents and business documentation the main risks for company X are identified. Experienced professionals from company X were asked during the interview session to provide input and to share their SC risk experience based on their expertise. Second source, business documents have provide practical examples in this study. With the help of this documents this study identified delivery performance as potential risk for company X that should be monitored in the future process. Therefore, these identified risks are relevant for company X. Table below shows the SCRs for company X and shows the disruption impact for company X.

Main risk:	Disruption risk:
Quality performance	High
Delivery performance	Medium
Automotive requirements	High
Design change of components	High
Sourcing complexity	High
Supplier dependency	High

Supply risk	High
Environmental risk	High

Further, a SCR can identified regular by using the risk management tool constantly. Distribution and regular use of the tool during the SCRM phase can help company X by identifying of potential/new risk. The SCRM phase encourages employees to think in terms of risk scenarios and risk situations, therefore providing them with more insight into and knowledge of risks. Further, knowing only the SCR does not contribute to successful SCRMP, therefore the following research question have been developed.

1.2 Which SCR assessment model is applicable for company X to assess supply chain risk?

An applicable risk assessment was necessary in this case, therefore all possible literature about SRCM was analysed, and the requirements for the tool were formulate by the company: the tool should be easy to use, assess or monitor risks, and easy to understand. As solution, this research implements the risk assessment method probability- impact matrix of (Thun & Hoenig, 2011), because this model assess SC risk, model is easy to use and easy to understand. Besides that, Thun and Hoenig (2011) use the assessment model also in an automotive industry in Germany as risk assessment model. From this reasons, this methodology fits the best with company X and their requirements. The risk assessment method determines risk by assessing it in terms of probability and business impact. The outcome of each assessed risk shows the risk level of each identified risk in colours, which can be used in the subsequent process of mitigating these risks.

1.3 How can company X continuously monitor SCR?

Monitoring risk is the fourth step in the SCRM, but limited attention has been paid to the monitoring phase mentioned by Blackhurst et al. (2008); Hoffmann (2012) in the academic world. Therefore, expanded attention has been paid to this step in this research. Further, the formulated requirements were the same for the monitoring method of this tool.

Company X can continuously monitor the SCR with the multi-criteria scorings procedure of (Blackhurst et al., 2008), after using mitigation strategies. Because, this method assess and monitor risks at the same time, and that is exactly what company X needs for monitoring commodity risk and other identified SC risks. Monitoring phase (in the Excel file) is classified on basis of risk categories and supplier performance. First, the responsible purchaser just enter the scores per risk category on basis of thresholds and per supplier to

assess the risk again and see the scores and the risk level after mitigation phase. The risk category scores can based on probability and occurrence (0-100). Then, the purchaser can enter the scores of the second, third and fourth quarter (in the future quarterly) per category and per supplier to monitor the improvements or declines per quarter. This approach ensures assessing risk for 2 times, transparency and helps the company to react efficiently to minimize the impact of risks.

The monitoring file is divided in four quarters and in the same structure, so the purchaser can perform easy the similar actions. Advice is, continuously using of SCRMP for a better performance, mainly in a dynamic supply chain to minimize potential disruptions in the future. Finally, continuously use of SCRMP cause continuously monitor SCR.

Main research question:

How can company X asses and monitor supply chain risk?

Answering the main research question, company X can assess and monitor the SCRs with the tailored risk management tool that is developed for the company. Therefore, this research paper presents a practical solution by developing a risk management tool. The SCRM process starts with identifying SC, all relevant risk must in this phase identified. Then, the constructed risk management tool assess and monitor risk in its supply chain. Namely, the risk assessment model implanted in the risk management tool shows the risk level and indicate the urgency of an identified risk, then company X can counteract the risks with tailored mitigation strategies, and so developing mitigation strategies and monitoring the risk would be possible with the risk management tool.

Finally, the reader should bear in mind that the study is based on the risks and risk categories of an automotive industry. Therefore, it should be noted that this research presents a categorisation and classification of risk that is specific to the automotive industry based on the needs of the firm and SCR literature. Additionally, once the focus is on other industries for example textile industry, the results might be different. From this reason, general risk statements for other industries is not possible in this case. Additionally, other industries that adopt a supplier risk assessment and monitoring methodology will need to define risk categories based on their own needs, industry, and supply chain type.[128] There is no ‘one-size-fits-all’ approach to assessing risk.[129]

[128]See Blackhurst et al. (2008)
[129]See Blackhurst et al. (2008, p. 148)

7.1 Further research for company

Future research should concentrate more on the external part of the supply chain to complete the risk management with external results from suppliers, as the results indicate that the supply chain of company X partly relies on suppliers' performance. It would be interesting to populate the risk management tool with risks identified by suppliers. The current risk management tool is based on academic theory and the findings of internal interviews, and could be expanded with those of external interviews to provide a transparent overview of how to improve both sides. In doing so, it is important to identify critical suppliers with the potential to disrupt the supply chain and those suppliers with high-risk degrees/levels in the risk management tool. This approach could provide a clear overview and could lead to improvements to the supply chain.

Finally, due to time constraints and the nature of the research process, there was no time to automate the tool in an ERP system. According to respondents' answers, time pressure and workload are issues in the current situation faced by the employees of company X. These issues cause negligence within the company; thus, the likelihood of infrequent use of the risk management tool is high. Future research could be conducted on implementing the tool automatically by allowing it to collect and enter the required data from available documents, with the aim of encouraging frequent use of the tool.

7.2 Future research academia

Future research could also focus on introducing the risk management tool in other industries. There are some articles available on the automotive and telecommunication industries but none on the fashion or chemical industries. In addition, there is a lack of practical research such as that found in the work of Blackhurst et al. (2008). There were also some difficulties in identifying a useful example in the field of SCRM.

8 Theoretical contributions

This research covers and redesign the risk assessment and monitoring phase. During the research process, this research found a gap in practical SCRM research papers in the field of SCRM. The availability of practical SCRM papers were limited and it was difficult to find well-defined practical SCRM papers, mainly detailed papers about SCR monitoring models. From this reasons, the student researcher had minimal opportunities and limitations in finding academic papers for this research. Therefore, this study add a practical SCRM research paper in the field of SCRM and has the goal to discuss the SCRM in detail and describe the construction of a risk assessment and monitoring model for the automotive industry in the Netherlands. This study gives insights in SCRM and shows the main SCRs in an automotive industry.

Other interesting new insight was found about the visualisation of the SCRM tool. The risk management tool present the results in colour visual manner. After developing and presenting the risk management tool, the company stakeholders experience that an overview with visual colours are more attractive in following the risk management tool then without colours. The colour visualisation approach provides better insight and structured overview and the risk are easy to detect in the tool for every stakeholder in the company, at a glance. Because, from specific colours (for example red, yellow, orange and green) the stakeholders can at a distance see what risks are exits in the supply chain. Therefore, in depth informations about the risk, explanations or specific informations are not necessary in the first instance, but in the future.

Other advantage of visualisation it time consuming. Most of the companies spent less time in SCRM, because of workload for example company X. However, this visual approach avoid time consuming. During a meeting or other discussions with the purchasers or other stakeholders in de SC, presenting the risk overview would be enough in the first instance. The stakeholders or the other parties can at a glance see what the risk are and in which level it operates. Then, developing mitigation strategies or discussing the SCRs would be easier and faster in the further process.

The opinions of the purchasers and the results shows that colour visualisation has a positive effect on the stakeholders at company X. So far, this research did not measure the visualisation effect on supply chain risk management. It would be interesting to measure the actual effect of visualisation in the SCRM and the impact on the performance.

9 Limitations

The limitations of this business research are discussed below.

- One of the main limitations of this research was data availability. Business documentation was used as secondary data, but company X has little documentation with which to explicitly determine the critical risk. The documentation used for this research shows some confirmation of the interviews and critical risk. However, not all identified risks could be confirmed by the documents, as related documentation was not at available at the company.
- Another limitation was the availability of SCRM papers or research regarding practical assessment and monitoring methodologies. There were limited papers available for constructing a reliable risk management tool that can assess and monitor risks in the supply chain.
- There was no time to automate the risk management tool in an ERP system. Therefore, the specialist must enter the data manually, and the possibility of not entering the data in the tool because of time pressure is high in the further. Additionally, the change of infrequent use of the risk management tool is therefore high.
- The final limitation was a time shortage. This research identified risk specifically on the situation of company X and the automotive industry. In addition, this research focused only on the relevant SC risks and is unable to encompass the entire rather risks in the supply chain.

9.1 Interviews and business documentation identifies SCR but there are some limitations.

The interview method that is constructed for the respondents identifies critical SCRs form respondents experiences. Further, the interviews were conducted with nine respondents and these respondents were selected based on experience and position in the company. Therefore, identifying critical risk was not difficult from respondent's experience. It is worth noting that the interview results are dependent on selected respondents and their experience/findings and could vary when the research is replicated with other respondents from the company.

Moreover, the business documentations were limited, so the researcher cannot indicate with certainly that the entire supply base has a medium-low performance in the current situation. Additionally, the business documentation titled "score card" were based on some performance aspects of the supplier for example delivery and quality performance, thus only these aspects are discussed in this study as critical SCR. Other source titled "portfolio

analysis" shows the commodity risk aspects and the supply risk about the specific commodity. These results rated on basis of interpretations of purchasers and probability impact each year. Basically, the results are internally based and there is not an external conservation with the supplier about the results.

Despite the limitations, the answers/results of this research lead to intended objective of the research. The research shows the critical SC risk and constructed a structured SCR management tool. Discussions about SCRs with the respondents were a revelation for them. Additionally, the results leads to interesting possibilities for follow-up research. For example, collecting external data from the supplier's perspective regarding to SCR or a further research based on upstream SCR in the automotive industry.

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Appendix I risk management model

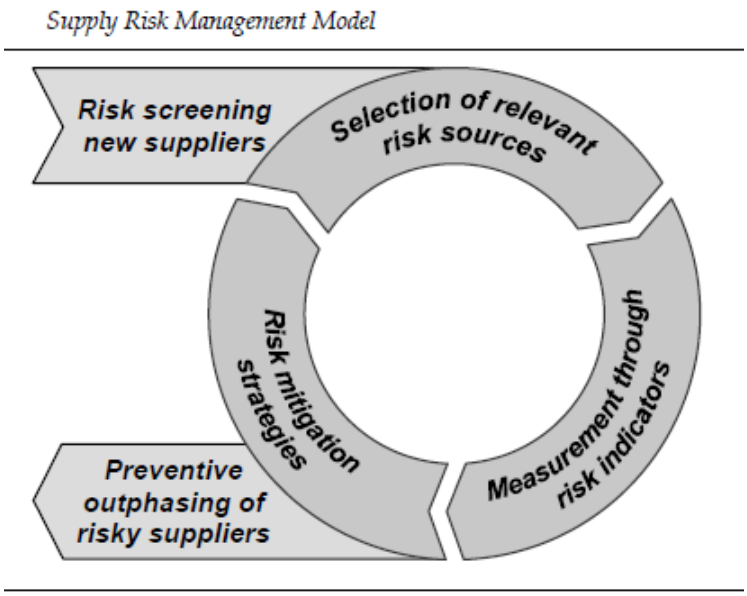


Fig. 7: Supply risk management model

Source: Hoffmann (2012)

Link supply chain risk overview:

https://www.draw.io/?lightbox=1andhighlight=0000ffandedit=_blankandlayers=1andnav=1#G1t8IAZBEm2UQlEQZ90BsHyQqnPp8V6KiH

Alternatively, see below Appendix III

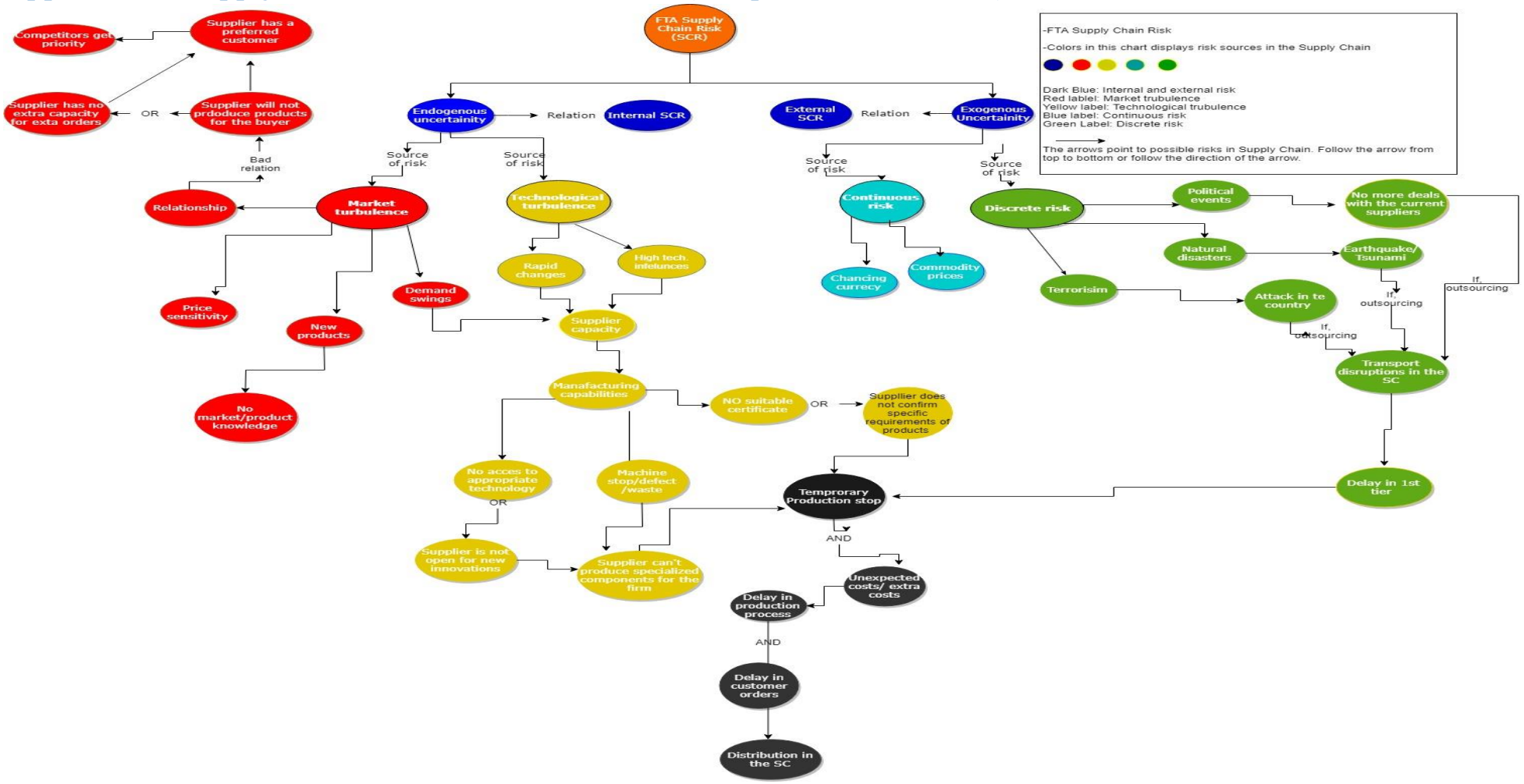
Appendix II: Interview questions

Interview questions related to identifying SC risk:

NR	SC risk background/identifying SR	Comments and explanations of respondents	Respondent input
1.	**Opening/introduction segment questions**		
1.1	Start with an introduction of yourself (the researcher) to the interviewee and acknowledge appreciation of the time for the interview.		
1.2	Explain the aim and topic of this research. Also, state that the results will be published anonymously and that the interview will have a huge contribution towards the research. Finally, ask for allowance to record the interview		
1.3	Can you explain your function or your role within the company?		
1.4	Can you also explain your role regarding to supply chain within the company?		
1.4	If you have connection with purchasing department. Can you also explain your collaboration with the purchasing department regarding to SC? And how is this collaboration going on?		
2	**Middle segment questions**		
	The questions in this segment go deeper in the subject to identify SC risk.		
2.1	What are supply chain risks according to you? (verification questions)		
2.2	Can you mention some SC risks and which one do you recognise as most critical SC risk for company X in your experience?		
2.3	What is the probability of occurrence of the (previous mentioned SC risks) and what where the effects of these risks for the SC performance of company X?		
2.4	What are the biggest disruptions that can occur at company X? Can you mention some critical SC risk in your career?		
2.5	What is the probability or occurrence of these disruptions in the current situation?		
2.6	Could you also describe an important SC risk situations with negative effect on both, company and business performance regarding to company X?		

2.7	What is the probability of occurrence of previous mentioned risk situations in the current supply chain?		
2.8	What were the impact of these SC risks for company X? And what are the opportunities to prevent these risks according to you?		
2.9	What kind of external risk occur in the current situation?		
2.10	Do you also recognise supplier risk problems in the supply chain? And what could be the impact for company X performance? Think about, quality, delivery, communication problems.		
2.11	How often does it happen that the suppliers cause risk in the supply chain.		
2.12	How important is 'assessing supply chain risk for company X?		
2.13	Is there any risk monitoring method or structure available to assess or monitor risk in the current situation?		
2.14	What are the biggest challenges within supply chain risk management for company X?		
2.15	What is the aim of Supply chain risk management? (verification question)		
2.16	When would you like to be able to use a supply chain risk management tool?		
	After assessing risk, we would also monitor these risks in the supply chain for better performance. Therefore, the researcher will also implement a monitoring methodology in the risk tool		
2.17	What are the main/ critical SC risk that needs to be monitored continuously?		
2.18	In which way can we monitor SC risk according to you?		
3	**Final/ conclusions segment questions**		
3.1	Is there anything that you want to add to this research or interview questions. Or other interesting discussions regarding to the supply chain risk topic?		
3.2	Thank the participant: Thank you for your time! I appreciate your participations in this research!		

Appendix III Supply chain risk overview based on (Chopra & Sodhi, 2004)



Supply chain risk overview

Appendix IV Multi-criteria scoring procedure approach by (Blackhurst et al., 2008)

Developed by the researcher Fig.7.1 Supply chain risk overview ' Fault tree analysis' source: (Trkman & McCormack, 2009)

Supplier risk monitoring tool

Category/subcategory	Supplier	Caliper assembly Supplier 1	Caliper assembly Supplier 2	Hub assembly Supplier 2	Hub assembly Supplier 3	Rotor Supplier 2	Rotor Supplier 4
	Percentage of supply	50	50	90	10	40	60
	Weight (percent)	Rating	Rating	Rating	Rating	Rating	Rating
Quality	60						
Defects/million	30	30	90	70	15	60	10
Ease of problem resolution	25	20	70	85	10	75	15
Product complexity	15	20	20	30	30	15	15
Timeliness of corrective action	25	20	90	85	15	70	15
Value of product	5	30	30	35	35	25	25
Total weights	100						
Overall supplier quality rating for each part		23.5	71.5	69.8	17.0	57.8	14.0
Disruptions/disasters	40						
Earthquake	5	15	35	35	5	35	65
Fire	30	15	80	80	70	80	30
Flooding	5	5	35	35	20	35	40
Labor availability	15	15	70	70	20	70	35
Labor dispute	10	20	85	85	35	85	25
Political issues	10	20	60	60	15	60	40
Supplier bankruptcy	15	5	10	10	35	10	35
War and terrorism	10	25	60	60	25	60	30
Total weights	100						
Overall supplier disruption rating for each part		15.0	60.0	60.0	38.0	60.0	34.3
Overall supplier rating for each part		20.1	66.9	65.9	25.4	58.7	22.1

Critical
High Risk
Medium Risk
Low Risk

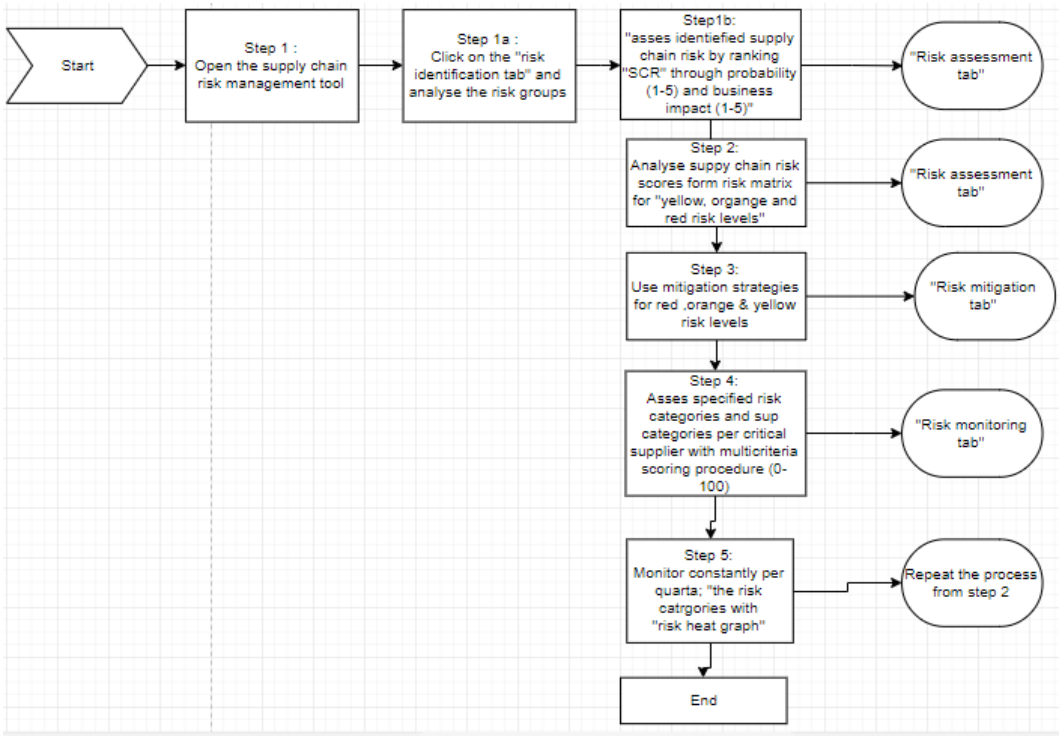
	Quality						Disturbution/Disasters									
	Defects/Million	Ease of Problem Resolution	Product Complexity	Timeliness of Corrective Action	Value of Product	Quality Mean	Earthquake	Fire	Flooding	Labor Availability	Labor Dispute	Political Issues	Supplier Bankruptcy	War and Terrorism	Distribution/Disasters Mean	Overall Rating
Category Weighting	60%						40%									
Sub-Category Weighting	30%	25%	15%	25%	5%	100%	5%	30%	5%	15%	10%	10%	15%	10%	100%	
Caliper Assembly	60.0	45.0	20.0	55.0	30.0	47.5	25.0	47.5	20.0	42.5	52.5	40.0	7.5	42.5	37.5	43.5
Hub Assembly	64.5	77.5	30.0	78.0	35.0	64.5	32.0	79.0	33.5	65.0	80.0	55.5	12.5	56.5	57.8	61.8
Rotot	30.0	39.0	15.0	37.0	25.0	31.5	53.0	50.0	38.0	49.0	49.0	48.0	25.0	42.0	44.6	36.7

Fig. 7.2: Risk monitoring tool Source: (Blackhurst et al., 2008)

Appendix V Supply chain risk management process

Supply chain risk tool process

The architecture of the entire supply chain risk management tool



Steps: risk identification, risk assessment, and risk mitigation ⬇
Step 1: Open the risk management tool and go to the ‘risk-identification step’
The identified risk is divided in tables such as: commodity risk, overall supply chain risk and performance risk. The results are identified by interviews and business documents.
The risk identification should done yearly. Additional risk can be added during the year in the risk-identification phase. After analysing the risk categories, go to the second step -> Risk assessment
Step 2: The supply chain risk is divided into three categories, operational, strategic, and environmental. The first two are internal risks and the last is external. In the risk assessment tab, give the identified supply chain risk (from risk identification) a number from 0 to 5. Each number has its own meaning; for example, 2 means ‘minor risk’ in the process. Assess the probability and business impact (0 to 5) for each identified risk. The legend in the risk management tool will navigate the analyst in the assessment process.
When each supply chain risk is assessed, the tool automatically measures the total score for the identified risk. The total score automatically shows the risk degree/level in colours (red, orange, yellow, and green), which are correlated to the risk degree (very high, high, or low risk). There is also a legend available in the tool that indicates per risk level de degree of risk. See ‘degree of risk’ and ‘risk level’ in the risk assessment tab.
Step 3: For the colours red, orange, and yellow, swipe to the tab ‘’risk mitigation’’. This tab describes many mitigation strategies that can be followed. These strategies are collected from the academic literature and in-depth interviews with employees from different disciplines.
The mitigation strategies are described in three sections, mitigation strategy 1, mitigation strategy 2, and mitigation strategy 3. Use each strategy step by step. If the first does not work, use the second. This will help employees use different strategies for different risk situations.

Supplier and commodity monitoring process **-> multi-criteria scoring procedure**

- Monitoring tool ensures smooth flow of products/materials through the supply chain.
- Monitoring tool can be used to improve the prediction and management of supplier-based disruption events in the supply chain.
- This tool focuses on the suppliers and commodities that have the potential to shut the supply chain down.
- Risk ratings must be tracked over time and risks should be monitored when they reach the unacceptable risk level.

Steps of the risk-monitoring process ⬇
Step 1: Choose the most critical commodity and suppliers. Enter the names of the supplier and the commodity. For commodity name, see A1; for the suppliers, see E2 to H2
Step 2: The risk-monitoring tool is divided into risk categories, subcategories, supplier percentage of supply weight, supplier rating, and total score
Step 3: The risk categories summarise the current supply chain risk of the company. (The risk categories are collected from the academic literature and in-depth interviews with a variety of internal employees). Further, each category is specified in subcategories. The subcategories show the more specific risks of that category. *Column A and B
Step 4: In this model, weights are used to indicate how important each risk category is with respect to disruptions affecting the company at the commodity level. The weights can be based on the probability of each category of disruption occurring.
Step 5: Once the categories and subcategories are defined and described, a rating must be established for the 'supplier risk rating'. Use here the most critical supplier for the specific commodity and asses the percent of supply per supplier by (0–100%*) *Row: E3 to H3 *Supplier rating is based on supply per supplier for that commodity. *The total sum of supplier percentage of supply weight is always 100%.

Step 6: Define the subcategories by importance of the categories using 0–100%, see 'risk subcategory weight'. If 'ease of problem solution' is an important aspect to monitor, assess this aspect higher than other subcategories, for example, 50%. *Row: D5 to D39 *The total weights is always 100%.
Step 7: Assess per supplier the risk rating per subcategory. The rating for each subcategory is based on a scale from 0 to 100, with a higher number indicating the supplier performance is worse in that subcategory. For example, 70 might indicate the supplier is poor in that subcategory. All scores range from a minimum of zero to maximum of 100. *(Column E,F,G,H) *For every single supplier assess the sub categories by ranking 0 to 100.
Step 8: The risk assessment score for each subcategory is found by first 'multiplying each supplier's rating on that subcategory by the percent of production purchased from the supplier', to get the individual supplier score on that subcategory (subcategory x supplier rating).
Step 9: The total scores (subcategory supplier score) are then added together to get the total score for that part and each subcategory. From the total score, the analyst can compare the performance for a specific subcategory. The overall supplier rating for each subcategory indicates the performance of each supplier individually. For example, E10 shows the performance of supplier 1 on quality. So that the analyst can analyse and compare the performance per supplier on that specific risk category. *Column I *Row E10 to H10
Step 10: All scores range from a minimum of zero to maximum of 100, with a higher score indicating a worse risk assessment on that risk category.
Step 11: The scores for each part are shown along with a total score and are colour based to quickly and easily visualise all the risk-assessment scores of each category. The tool uses different colours to highlight the severity of a particular risk category.

>70 = poor performance (red) >50 = high performance (orange) >20= medium performance (yellow) <20 = good performance (green)
Step 12: If all risk subcategories are assessed, then the analyst can quickly and easy analyse the most critical risk performance per supplier on that commodity via the visual colour table (Blackhurst et al., 2008).
Step 13: Repeat this risk assessment per quarter for each critical commodity that has the ability of shutting down the supply chain. Check the next quarter for improvements and assess the performance again, repeating this action each quartile for better results and performance. Continuous monitoring ensures a better management of supply chain risk (Blackhurst et al., 2008).

Excel version SC risk management tool

Risk tool.xlsx

Appendix VI Construction of risk management tool for company X

Risk identification

Commodity risk

	Hose assembly	Motor	Small turning parts	Bodies	Seals	Metal casting	TR Plunger	Hardware	Tupes	Bases	Stamped Parts	Large turning parts
Design	HR	MR	MR	HR	MR	HR	MR	MR	HR	HR	HR	MR
Specefic requirements (Iso & TS16949)	HR	MR	MR	HR	MR	HR	MR	MR	HR	HR	MR	MR
Intellectual proporty	MR	HR	LR	LR	MR	LR	LR	HR	LR	LR	LR	LR
Number of potential suppliers	LR	LR	LR	MR	MR	LR	MR	LR	HR	LR	LR	LR
Alternative sourcing	MR	HR	LR	MR	MR	HR	MR	LR	MR	LR	MR	LR
Specification and verification	HR	HR	MR	HR	MR	HR	MR	MR	HR	MR	HR	MR
Gut feeling factor	DNA	N	N	HR	N	N	DNA	N	N	N	N	N
Supply risk total score	7,4	6,6	2,8	7,2	5	6,6	4,4	4	6,8	4	6	2,8

HR= High risk
MR= Medium risk
LR= Low Risk
N= Natural

Overall supply chain risk

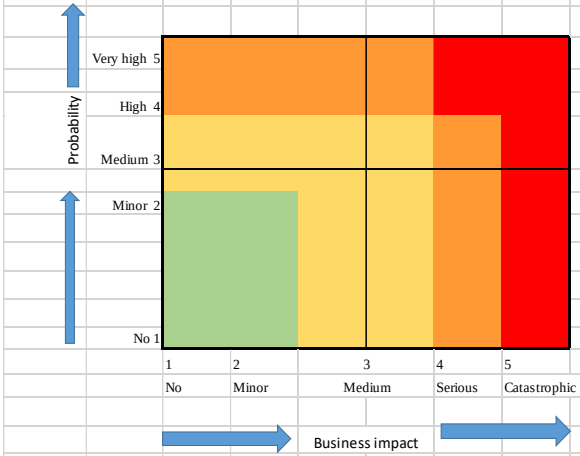
Operational	SCR	Disruption probability	Critical because
	Quality performance	High	• Direct related to the component
	Delivery performance	Medium	• Direct related to component and delivering
	Specific requirements	High	• Influence the direction of supply chain flow
	Design of components	High	• Direct related to components
	Sourcing complexity	High	• Limited alternative sourcing
	Minimal knowledge about indirect products	High	• Ensures high risk in the SC
Strategic	Supply risk	High	• Dependency on suppliers are high
Environmental	Environmental risk	High	• Most of the supplier are based abroad
	High dependency in the automotive industry	High	• Company X is dependent on both, end

Performance risk

Score card results	Supplier 1	Supplier 2	Supplier 3	Supplier 4	Supplier 5	Supplier 6
Quality performance	C	A	A	A	B	A
Delivery Performance	D	D	A	B	B	B
Payment term performance	A	A	A	A	A	A

Quality Grade	Supplier Status	Standard	Action Taken
A	GREEN	90%~100%	No Action - Vendor consistently conform to the standard.
B	BLUE ALERT	70%~89%	Vendor has minor non-conformances. Possible Actions Required.
C	YELLOW ALERT	60%~69%	Vendor has major non-conformances. Supplier Actions required within 30 days.
D	RED ALERT	<60%	Vendor has major non-conformances. Potential Actions (Depending On Severity) In Addition To Above. 1. New Business Hold 2. Resourcing by Actuant

Risk assessment (1/2)



Legend:
1= No risk
2= Minor risk
3= Medium risk
4= Serious risk
5= Castrophic

Supply chain risk	Probability	Business Impact	Risk score
Operational risk	0	0	0
Temporary disruption through supplier can cause problems in the SC	0	0	0
Structural disruption through supplier can cause problems in the SC	0	0	0
Scarcity of raw material can cause disruptions in the SC	0	0	0
Lack knowledge about indirect elements in the production process can cause issues in the SC	0	0	0
Delays in material flows can cause issues in production process	0	0	0
Supplier material quality can cause disruptions in the supply chain	0	0	0
Disruption in internal transport vehicles cause problems in the and production flow	0	0	0
Disruption in the warehouse building cause problems in the SC	0	0	0
Disruption labour in the production process can cause issues in the production process	0	0	0
Not releasing of suppliers while production process	0	0	0
Late or early delivering can cause issues in the production process- and warehouse	0	0	0
Strategic risk	0	0	0
Dependency on customer with "high turnover" can cause issues in the supply chain	0	0	0
Single sourcing of "critical items or high volume items"	0	0	0
Short terms contract with strategic supplier instead of long term contracts	0	0	0
Environmental	0	0	0
Terrorism, natural disasters, can cause disruptions in SC	0	0	0
Currency fluctuations can cause disruptions in SC	0	0	0
Raw material price increase of a high volume item	0	0	0
Transport risk can cause delay in production process	0	0	0
Bankruptcy of a supplier can cause disruptions in the SC	0	0	0
Not satisfying sustainability aspects of automotive industry can cause problems in the supply chain	0	0	0
Second tier in the SC can cause issues in the supply chain	0	0	0

Risk assessment (2/2)

Degree of Risk	Risk level	
Very high	Red	Risk mitigation required to level medium or low. If the risk is not mitigated, monitoring and making a contingency plan is necessary.
High	Orange	Risk mitigation required to level medium or low. If the risk is not mitigated, monitoring and making a contingency plan is necessary.
Medium	Yellow	Risk mitigation to level low is optional, monitoring is required
Low	Green	No further risk mitigation is required
		(Risk= Probability (of the event) *Business Impact (of the event))
Source: Ericsson		

Risk mitigation (1/3)

NR	Supply chain risk/ Supply risk	Risk mitigation strategies	Risk mitigation strategies	Risk mitigation strategies
1	**Temporary disruption through supplier can cause problems in the SC**	Holding some extra inventory for ''specific items'' that can cause disruptions in the SC ''high critical items''	Use multiple sourcing for high volume products and single sourcing for low volume products	
2	**Structural disruption through supplier can cause problems in the SC**	Holding some extra inventory for ''specific items'' mainly for customers with a high impact on the turn over	Use multiple sourcing for high volume products and single sourcing for low volume products	If possible, on site risk assessment/supplier quality check. Source while the process for other potential suppliers.
3	**Second tier in the SC can cause issues in the supply chain**	Include the importance of second tier in the supplier selection process, firstly analyse the supply chain of the potential supplier before	Analyse suppliers with a long distance and search for suppliers with a good performance in the SC	
4	**Late or early delivering can cause issues in the production process- and warehouse**	Involve as purchaser in the ''product and process development validation'' phase. Communicate with the customers and disciplines internally, the possibilities regarding to available materials for that component	Discuss with the engineers the alternatives for possible raw materials and check which supplier is capable to deliver/produce this products for Power-Packer	If possible, specify the non critical items to end customer. For example, there is a lot of simple" tape" of ''pin'' types in the automotive industry . Using an alternative tape or pin in stead of production stop.
5	**Lack knowledge about indirect elements in the production process can cause issues in the SC**	Check before buying or production process the product specification.	Specify the non-Boom- materials. Appoint a responsible person for this part that can specify these materials	
6	**Supplier material quality can cause disruptions in the supply chain**	Supplier audit/self assessment at expected level, check the outputs and communicate to supplier for improvement opportunities	Repeat supplier assessment over time and do requalification on part level according to automotive requirements	Requalification parts level per quality check by Quality Engineers
8	**Disruption labour in the production process can cause issues in the production process**	Maintain excess flexible capacity in existing plants	Employing team leaders or employers who can work on any station. Besides reducing the need for extra station - specific workers	Balancing capacity and inventory depending on the cost of the products.
9	**Dependency on customer with ''high turnover'' can cause issues in the supply chain**	Building trust (fairness) over time with the supplier	Continuously Intensify communicate with the supplier avoid disruptions in the SC	

Blue colour: Mitigation strategies from academic literature
Yellow color: Mitigation strategies from interviews

Risk mitigation (2/3)

10	**Transport risk can cause delay in production process**	Use for each new supplier the risk assessment tool and assess the environmental risk for that supplier. "Avoid critical countries"	If the risk level show a red, orange or yellow. The probability for a disruption in the supply chain is high "for that supplier".	If possible, check other potential supplier in the local market or find supplier with minimal environmental risk in the area
11	**Terrorism, natural disasters, can cause disruptions in SC**	Use for each new supplier the risk assessment tool and assess the environmental risk for that supplier. Do this also for the commodities!	If the risk level show a red, orange or yellow. The probability for a disruption in the supply chain is high.	If possible, check other potential supplier in the local market or find supplier with minimal environmental risk. Or select a second supplier as an alternative
12	**Single sourcing of "critical items or high volume items"**	Firstly, discuss with different disciplines internally "where are we going to source"	For long term collaboration (strategic partner), long terms contract ensures low risk in the supply chain	Be stuck the material price in the contract while the collaboration
13	**Transport risk can cause delay in production process**	Combine the inventories with different transport modes to cover delays in the supply chain and avoid critical countries!	Use for each new supplier the risk assessment tool and assess the environmental risk for that supplier	If the risk level show a red, orange or yellow. The probability for a disruption in the supply chain is high. If possible, check other potential supplier in the local market or find supplier with minimal environmental risk.
14	**Bankruptcy of a supplier can cause disruptions in the SC**	Firstly, request a payment behaviour of the supplier. Preferably while the supplier selection procedure.	According to academic world, supplier self assessment is a successful mitigation strategy regarding to financial risks	
15	**Not releasing of suppliers while production process**	Have always an alternative supplier, if the product has a high value.	Check the opportunities for improvements for that supplier that has failed in the process	
16	**General or specific test equipment broken**	"Use test equipment at other facility	Buy or rent equipment at external party"	

Risk mitigation (3/3)

17	**Dependency on customer with ''high turnover'' can cause issues in the supply chain**	Building trust (fairness) over time with the supplier	Continuously intensify communication with the strategic partner
18	**Disruption in internal transport vehicles cause problems in the and production flow**	" Permanent replacement vehicles by the supplier	Internal transport vehicles will be replaced as soon as possible by the supplier. There is no fixed response time, but based on experience problems are solved within a work day. To get by in the meantime. it is possible to have
19	**Delays in material flows can cause issues in production process**	Decentralize inventory of predictable for lower value products	Centralize inventory of less predictable for higher value products
20	**Currency fluctuations can cause disruptions in SC**	Check before collaboration the currency status of the country. If the country do not have a stabile currency status. Choose a other supplier or make long term deals specific price agreements.	
21	Not satisfying sustainability aspects of automotive industry can cause problems in the supply chain	Implement sustainability requirements in the supplier selection process to avoid risk in the further process	

Risk monitoring

Commodity:	Q1								
Risk category	Sub category	Risk sub category weigh	Sub category weights	Total supplier rating	Supplier risk ratin	Supplier 2 rating	Supplier 3 rating	Supplier 4 rating	Total score
Rating				0%	0%	0%	0%	0%	Supplier rating per sub category x supplierrating (heat graph)
Quality		0%							
	Defects/ rejected ppm		0%		0	0	0	0	0
	Ease of problem solution		0%		0	0	0	0	0
	Timeliness of corrective actions/responding		0%		0	0	0	0	0
	Repeated defect rate		0%		0	0	0	0	0
Total weights			**0%**						
Overall supplier rating for each part					**0**	**0**	**0**	**0**	
Manufacturing risk		0%							
	Changes product design		0%		0	0	0	0	0
	Machine breakdown		0%		0	0	0	0	0
	Supplier material		0%		0	0	0	0	0
Total weights			**0%**						
Overall supplier rating for each part					**0**	**0**	**0**	**0**	
Supplier dependence		0%							
	Supplier manufacturing capacity		0%		0	0	0	0	0
	Inflexibility of supply source		0%		0	0	0	0	0
	Dependency on a single source of supply		0%		0	0	0	0	0
Total weights			**0%**						
Overall supplier rating for each part					0	0	0	0	
Procurement		0%							
	Exchange rate risk		0%		0	0	0	0	0
	Part price		0%		0	0	0	0	0
	Short term contracts instead of long terms		0%		0	0	0	0	0
Total weights			**0%**						
Overall supplier rating for each part					**0**	**0**	**0**	**0**	
Disruptions/disasters		0%							
	Earthquake & Flooding & Terrorism		0%		0	0	0	0	0
	Supplier bankruptcy		0%		0	0	0	0	0
	Transport		0%		0	0	0	0	
	Labour availability		0%		0	0	0	0	0
Total weights			**0%**						
Overall supplier rating for each part					0	0	0	0	

>70 = poor performance
>50= Medium performance
<20= Good performance

Appendix VII Supplier locations

Overall Supplier locations	Commodity Hose assemblies	Commodity Motors	Commodity Small turning parts	Commodity Bodies	Commodity Metal casting	Commodity Seals	Commodity TR plungers	Commodity Hardware	Commodity Stamped Parts	Commodity Tubes	Commodity Large turning parts	Commodity Bases
Germany	x	x	x			x		x	x		x	x
England												
Turkey							X				x	
Spain			x			x		x				
China		x		x	x		x	x		x	x	x
USA						x						
France	x	x	x	x	x	x	x	x			x	
Sweden												
Brazil												
Italy		x		X								
South Korea			x									
Mexico												
Netherlands					x	x		x		x		x

Appendix VIII Examples of "what if questions"

What if Questions
What might happen if a particular supplier could not deliver for a month?
What if a supplier raised prices by 20% ?
What if demand went up or down 20%?
What is a customer delayed cash payment by a month?
What if a key supplier will not deliver the specialty components?
What if the communication is bad in the relationship, and the supplier delivers fewer prodcuts?
What if single supplier has not the capacity to make the goods, suddenly?
What if the plant of the supplier burns down?
What if
What if
What if
What if
What if
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What if
What if

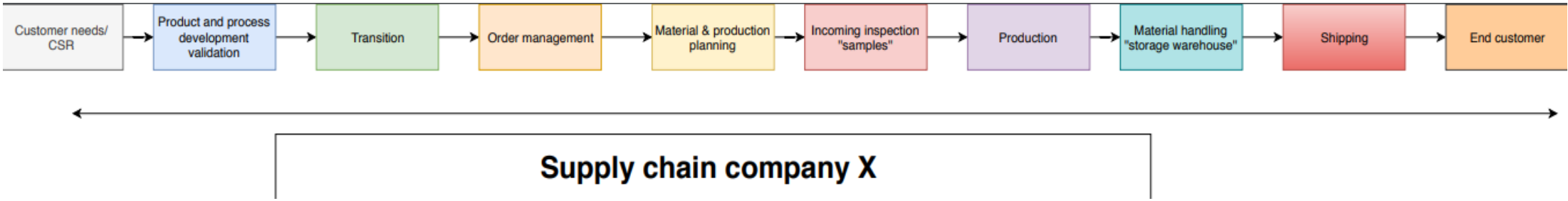
Appendix IX Assessing the impact of various Mitigation strategy

Assessing the impact of various Mitigation strategy	Disruptions	Delays	Forecast risk	Procurement risk	Receivable risk	Capacity risk	Inventroy risk
Add capacity							
Add inventory							
Have redundant Suppliers							
Increase responsiveness							
Increase flexibility							
Aggregate of pool demand							
Increase capability							
Have more customer accounts							

Greatly Increase Risk ↑ ∨ Decrease risk

Increase risk ∧ ↓ Greatly Decrease Risk

Appendix X Supply chain process of company X



Appendix XII Interview results

Table 4.1: Identified supply chain risks

Respondents	Identified SC risks in bullet points	Summarised findings from respondent
Product line director	• Quality • Dependency	The product line director stressed the importance and consistency of the quality of the materials provided by suppliers and dependency on suppliers. Company X is dependent on suppliers because "we cannot produce the components by ourselves". We are specialized in the assembly of components. Basically, we find it necessary to work together with external parties. Furthermore, most product specification are fixed, for example the material of the components or the specification. However, there are some difficulties with the consistency of suppliers in providing the correct material according to specifications. Risks include suppliers not being capable of producing according to the requirements of the automotive industry or not being able to produce specialized products for company X or lastly material scarcity could an issue in the SC.
Operations leader	• Design changes	The operation leader identified the risk of packaging definition for suppliers' material. Risk is high if there is not alignment (e.g. alignment concerning what types of packaging materials should be used) between suppliers and company X's logistics warehouse; this aspect can negatively affect product quality. Because, we have also packaging requirements in the

		automotive industry, the products must so package that the chance of disruption minimal is. Another risk indicator is the design change on the part of an OEM (e.g. a change of even 1 mm in the design of a component). However, the risk in this example concerns whether the supplier is capable of reproducing the components or has the extra capacity required doing so, and other consequence is the components must be released again, to ensure the quality of the components. We cannot sell the products without an approval from the engineering and supplier quality employees. Thus, we need to release the products for the second time. We experience that design change takes a lot time and makes the work pressure higher and higher in the company.
Project manager operations	• Collaboration abroad • Plant in Turkey • Political issues	During the interview, the project manager stressed the importance of the plant in Turkey. A current example of SCR is the decision to move the automotive plant to Turkey, which partly destroyed the supply chain. Project manager indicated that most European companies do not want to cooperate with a plant in Turkey due to political issues; this is an example of environmental risk.[130] Suppliers (from Germany) did not deliver materials, and finding new suppliers around Turkey was difficult because of limited offer in the country. This had a negative impact on the company's performance. Project manager mentioned

[130]See Jüttner et al. (2003, p. 11)

		also that profit margin and delivery reliability decreased and that raw materials were scarce.
Engineering director	• Design change • Quality issues with suppliers • Late involvement in the design phase • Automotive requirements	Engineering director indicated there is a high degree of dependence on suppliers, which is a critical risk in the automotive industry. Company X buys components from suppliers, assembles them, and sells the assembled components to OEMs in the automotive industry. Basically, company X is dependent on external parts of its supply chain. Furthermore, one of the respondents (of this research) had an interesting question about using alternative parts to prevent disruptions for the engineering. The answer from the engineer was using alternative parts is not a standard approach or solution to avoiding risk in the automotive industry because, for example, it is not known how a substitute material will respond to a specific oil or other liquid elements in a motor. He stated that one material working well for product A does not mean it would also work for product B. Thus, use of a substitute depends on material specifications. Moreover, if company X does this regularly (which often happens now), complaints will increase, quality will decrease, and products will have to be pulled from the market, which will affect the supply chain's performance. Hereby, the requirements of the automotive industry could influence the flow of the SC, we cannot use every alternative components to solve a problem. It is forbidden and only approved items or material can be used, and if we do not have the material now. Then, we will just have a good conversation with the suppliers.

		Second critical risk identification was that the respondent stressed the product design change in the product cycle. Because, the components must be re-released by the supplier and the OEM every time, by every changes that are made. Such change can occasionally take months, during which time the company cannot deliver goods to OEMs in the automotive industry.
Indirect procurement manager	• Environmental risk • Quality of materials	An example of a current risk associated with sourcing is the Brexit. Company X has a supplier based in the Netherlands, but this supplier sources material from the UK. The risk is that legislation could change, requiring agreements and material price agreements to be revised. This risk situation results in uncertainty to the company's supply chain. We are constantly working. A second issue in our supply chain is the mutual communication internal and external. We have many issues with this aspect and we experience that this aspect frequent disrupt the flow in the SC. For example, an internal failed communication: everyone plays as a purchaser in this company, they buy something or agreements are made with the supplier without consultation with the purchasers. If this happen we can “firefighting” continuously as department. Also external, without any consultation with the purchaser, the employees take actions with the suppliers about materials or components.
Senior director sales	• Single sourcing • Dependency on suppliers • Automotive requirements	The senior director responsible for six teams indicated that risk mainly exists in the sourcing of materials. He said that the company is responsible for the complexity of its supply chain. If the company selects suppliers abroad, the risk level could become higher,

	• Dependence on OEMs •	the supply chain could become more complex and the environmental risk could become higher. The specialist also mentioned 'high dependency in the automotive industry'; he noted that the suppliers sometimes wish to be monopolistic and to produce a product itself and sell it to the OEM. Thus, considering 'how many alternatives there are in the market' is a relevant question for the purchasers. Another risk in the supply chain for company X is single sourcing of critical items. The director reports that single sourcing of critical items causes significant disruptions in the SC. We have now problems with a single supplier that produced components for an important OEM (BMW). The supplier cannot deliver the components because of miss management and lack of capacity inside the company. Actually, company X is now dependent on the supplier, and no components essentially means no production. This disruption also affects the production process of the OEM, just like the present example.
Manager logistics	• Disruptions in the warehouse • Disruption in internal transport • Broken specific/general test equipment	In contrast to other respondents, the logistics manager reported that the logistics department had few issues with upstream SCRs because they are mainly focused on the products/components that come in to the warehouse from suppliers and the transportation of assembled goods to the OEM. However, as a department, Logistics (Expediters) are responsible for detecting differences in the goods delivered by suppliers, which is referred to as 'temporary disruption on the part of a supplier'. For example, when there is difference between delivered goods or not all components are delivered, the likelihood of

		production being halted is high, as the company only uses safety stock for critical components. The manager also noted that today's suppliers are efficient and respond quickly. However, the consequences of disruptions could be significant for both company X and OEMs in this case.
Manufacturing engineering manager	• Manufacturability of products • Transportation	The product line director agrees that monitoring the supply chain ensures better performance. Manufacturing engineering manager also indicated that the main risk exists in the rinsing and cleaning of materials/components (e.g., component bodies the main part of an assembled product). Cleaning and rinsing components are actually the responsibility of suppliers. However, suppliers do not always clean the components thoughtfully that they deliver. For example, actually the main issue occurs during the transportation of products from China to the Netherlands. Unclean means that the components are dusty or that some components have had oil spills on them. Components from China are transported by boats and trucks, so the distance is quite significant. Thus, it is logical that products may be unclean or fail to satisfy the requirements of automotive industry. Thus, company X is responsible for the components, and extra cleaning in such cases. The extra rinsing or cleaning that we do costs extra. We do not talk about 100 euros but about thousands of euros. It is strict forbidden to deliver dirty products to OEMs in the automotive industry. To conclude, the chance of destroying the other components through assembling unclean components is high. Therefore, the company

		is very strict and precise in its factory standards regarding components provided by suppliers.
Sales support manager	• Requirements of the automotive industry • Dependency on supplier • Quality of materials	The sales support manager explained that specifying what the supplier must produce and what is expected of them is important. Sales support manager noted that the risks are higher in the automotive industry when compared to the truck industry. The requirements of this industry are strict, and quality is the most important aspect. In the current situation, relationships and alignment with external parties are important. When there is lack of alignment between suppliers and company X, the chance is high that the supplier does not know the requirements of an automotive industry, which will result in quality problems and consequences for the SC. She reported that company X had found that as well new as current suppliers had limited understanding of the requirements of the automotive industry with regard to automotive industry requirements, which leads to miscommunications and disruptions in the supply chain. As has been mentioned frequently, quality is the most important aspect in the automotive industry. A single quality problem or requirement issue requires starting the entire production process over. Greater attention to quality and collaboration with the suppliers could help to solve such problems.

Appendix XIII

Risk categories	Subcategory
Quality	Defects/rejected ppm (parts per million)
	Ease of problem solution
	Timeliness of corrective actions/responding
	Repeated defect rate
Manufacturing risk	Changes in product design
	Machine breakdown
	Supplier material
Supplier dependence	Supplier manufacturing capacity or flexibility of supply source
	Sourcing complexity
	Single source of supply
Procurement	Exchange rate risk
	Part price
	Short- instead of long-term contracts with strategic suppliers
Disruptions/disasters	Earthquake, flooding, and terrorism
	Transport/delivery
	External automotive requirements