UNIVERSITY OF TURKU

ABSTRACT

	Bachelor's thesis
X	Master's thesis
	Licentiate's thesis
	Doctoral dissertation

Subject	Operations and Supply Chain Management	Date	5.11.2021
Author	Eemil Säynäslahti	Number of pages	167+appendices
Title	Assessing Total Cost of Supply Chain Risk: Constructive Study at a Semiconductor Company		
Supervisors	Associate Prof. Harri Lorentz Ph.D. Vesa Kilpi		

Abstract

This master's thesis provides tool for supply chain risk impact identification and assessment in monetary terms by combining the total cost of ownership (TCO) approach with a selected toolbox from supply chain risk management (SCRM) literature as one of the very few examples of synthesis from these two literature fields.

The *research design* of the study is based on the constructive research process (CRA) which has not seen extensive usage in SCRM literature. The SCRM construction created via synthesis of literature is tested and further developed in a qualitative and constructive single case study utilizing three supply chains of the Client company, a Finnish semiconductor manufacturer with heavy footprint on the automotive industry.

As the main *key finding* of the study, a SC risk analysis tool combining the TCO approach with the SCRM framework is found possible to be constructed. The tool is discovered to provide broad and relevant insight for decision-making but suffering from lack of novel risk findings, complicatedness, and high usage of time. Furthermore, support is established for the usage of absolute business measures rather than relative scales for monetary prioritization of risk. In addition, the limiting effect of scope-driven approach for comprehensiveness of risk analysis and the difficulties with SCRM tools in the remote working are pondered.

The main *research contribution* for academic audience is created by providing a synthesis of SCRM and TCO frameworks which has been lacking practical applications despite a prominent expectations of the literature. Furthermore, contribution is presented for three other research gaps highlighted by SCRM literature: creation of supporting tools for SCRM cost-benefit analysis, robust and systematic tools for risk identification and assessment, and further empirical validation of theoretical SCRM concepts.

The main *managerial implications* are provided by answering the practical needs of the Client company. In a more general level, the tool could see usage in differing contexts as well thanks to the comprehensive walk-through of the process and the review of limitations for applicability. Furthermore, practical implications can be drawn from the supporting risk classifications of the tool mirroring the risk environment studied – not to forget the explored potential of CRA in finding practical solutions for SCRM-needs.

Finally, four *future research* ideas related to revisiting the Client company, integration of entire SCRM process, testing of the constructions in other industrial settings as well as further research combining SCRM and TCO literatures are proposed.

Key words	Supply chain risk management, total cost of ownership, risks, constructive research approach, semiconductor industry, automotive industry

TURUN YLIOPISTO

TIIVISTELMÄ

	Kandidaatintutkielma
X	Pro gradu -tutkielma
	Lisensiaatintutkielma
	Väitöskirja

Oppiaine	Toimitusketjujen johtaminen	Päivämäärä	5.11.2021
Tekijä	Eemil Säynäslahti	Sivumäärä	167+liitteet
Otsikko	Toimitusketjuriskin kokonaiskustannuksen arviointi: Konstruktiivinen tutkimus puolijohdeteollisuuden yrityksessä		
Ohjaajat	Apulaisprofessori Harri Lorentz KTT Vesa Kilpi		

Tiivistelmä

Tämä pro gradu -tutkielma tarjoaa työkalun toimitusketjuriskien tunnistamiseen ja rahalliseen arviointiin yhdistämällä kokonaiskustannusten hallinnan (TCO) lähestymistavan valittuihin työkaluihin toimitusketjujen riskienhallinnan (SCRM) kirjallisuudesta yhtenä harvoista esimerkeistä, jotka yhdistävät nämä kaksi kirjallisuuden suuntausta.

Tutkimusstrategia perustuu konstruktiivisen tutkimukseen (CRA), joka ei ole nähnyt laajaa käyttöä SCRM-kirjallisuudessa. Tieteellisen kirjallisuuden synteesin avulla luotu SCRM-konstruktio testataan ja edelleen kehitetään kvalitatiivisessa ja konstruktiivisessa tapaustutkimuksessa, joka hyödyntää kolmea toimeksiantajayrityksen toimitusketjua. Toimeksiantaja on suomalainen puolijohdevalmistaja, jolla on vahva jalansija autoteollisuudessa.

Merkittävimpänä *tutkimustuloksena* toimitusketjuriskien analyysityökalu, joka yhdistää TCO-lähestymistavan SRCM-viitekehykseen, todetaan mahdolliseksi luoda. Työkalu tarjoaa laajaa ja relevanttia tietämystä päätöksenteolle, mutta kärsii uusien riskilöydösten puutteesta, monimutkaisuudesta ja korkeasta ajankäytön tarpeesta. Tukea annetaan myös absoluuttisten liiketoiminnallisten mittarien käytölle riskien priorisointiin suhteellisten skaalamittarien sijasta. Lisäksi pohditaan fokusoituneemman lähestymistavan rajaavaa vaikutusta riskianalyysin holistisuudelle sekä SCRM-työkalujen soveltamisen haasteita etätyöskentelyssä.

Pääasiallinen *tieteellinen kontribuutio* akateemiselle yleisölle luodaan tarjoamalla SCRM- ja TCO-viitekehysten synteesi, joka ei ole kirjallisuuden odotuksista huolimatta tarjonnut juuri käytännön sovellutuksia. Kontribuutiota esitetään myös kolmelle muulle SCRM-kirjallisuudessa korostetulle tutkimuspuutteelle: tukevien työkalujen luomiselle riskienhallinnan kustannus-hyötyanalyysille, kestävien ja systemaattisten työkalujen laatimiselle riskien tunnistamiseen ja arviointiin sekä teoreettisten SCRM-konseptien lisävalidoinnille empiirisesti.

Pääasiallinen *käytännön kontribuutio* tarjotaan vastaamalla toimeksiantajayrityksen käytännön tarpeisiin. Yleisemmällä tasolla, luotu SCRM-työkalu voisi olla käyttökelpoinen jopa toimeksiantajasta eroavissa konteksteissa laajan prosessin läpikäynnin sekä sovellettavuuden rajoitteiden katsauksen ansiosta. Lisäksi käytännön kontribuutiota tarjoaa tutkittua riskiympäristöä heijastelevat ja työkaluun sisältyvät riskien luokittelut. Unohtaa ei sovi myöskään todettua CRA-lähestymistavan potentiaalia käytännön ratkaisujen löytämiseksi SCRM-tarpeisiin.

Tutkielmassa tunnistetaan myös neljä *jatkotutkimusideaa* liittyen toimeksiantajayrityksen seurantaan, koko SCRM-prosessin integraatioon, konstruktion testaamiseen muilla toimialoilla sekä SCRM- ja TCO-kirjallisuudet yhdistävään lisätutkimukseen.

Avainsanat	Toimitusketjujen riskienhallinta, kokonaiskustannusten hallinta, riskit, konstruktiivinen tutkimus, puolijohdeteollisuus, autoteollisuus

UNIVERSITY
OF TURKU
Turku School of
Economics

ASSESSING TOTAL COST OF SUPPLY CHAIN RISK

Constructive Study at a Semiconductor Company

Master's Thesis
in Operations & Supply Chain
Management

Author:
Eemil Säynäslahti

Supervisor:
Associate Prof. Harri Lorentz
Ph.D. Vesa Kilpi

5.11.2021
Turku

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

1.1 Background

1.1.1 Practical motivation

Japanese owned Finnish company ('Client') specialized in the sensor technology of the electronics and semiconductor industry for mostly automotive applications and holding a significant share of its segment, introduced a following challenge for the author in the beginning of 2021. The Client has been increasing the level of complexity, especially due to new chains involving outsourced manufacturing, in its supply chains in the last 10 years. However, this development has not been happening without any struggle, as severe supply chain disruptions and risks events had challenged the operational efficiency and profitability of these novel supply chain designs.

Simultaneously, the management of the Client has not always found convenient to decide on mitigating activities: One of the major benefits of these activities, the reduced risk impact, has rarely been assessed in monetary terms – the language of the business cases. Due to these circumstances, the interest to implement new tools to identify the risks in the supply chains and assess them in monetary terms as well as applying these tools to supply chains recently implemented or currently being planned has been emerging.

1.1.2 Research gaps

During the same era of as the development of the supply chain designs of the Client, the concepts, and practices of *supply chain risk management* (SCRM) has attracted increasing attention. The practitioners of supply chain management (SCM) have expressed growing interest in the field and, simultaneously, the amount of published research papers of the field has been increasing with a high growth rate during the first decades of 21st century. (Colicchia & Strozzi 2012, 403; Fan & Stevenson 2018, 211.) Numerous trends, not unfamiliar to the Client either, including increased complexity of supply chains generated by accelerated globalization and use of outsourcing, focus on efficiency as well as increased supply chain integration, have increased the relevance of risk perspective in SCM during the last two decades (Jüttner et al. 2003; Norrman & Jansson 2004, 434; Rao & Goldsby 2009, 98; Vanany et al. 2009, 17). The negative effects of the trends to the performance of supply chains in general can be identified from popular incidents of the last two years; most notably the effects of Covid-19 pandemic starting from the Spring 2020 and the incident of container ship grounding at Suez Canal on March 2021 (Hoek 2020a, 353; Ivanov & Dolgui 2020, 2911; Ft.com 26.3.2021). Thus, there seems to be widely accepted view in both academic and business community, that SCRM activities can be considered a critical capability in modern environment which can lead to an increased competitiveness, improved market position and positive effect on financial performance (Colicchia & Strozzi 2012, 210; Fan & Stevenson 2018, 403).

Despite the increasing interest of the practitioners and growing rate of new academic research, four distinctive research gaps which are closely interconnected to the identified needs of the Client, can be extracted from the field of literature. Together with the inter-related needs of the Client, they act as the motivator for the scope and research questions of the study. The main research gaps identified are summarized in table 1.

Table 1. Identified research gaps.

Research gap 1	Development of tools to measure costs and benefits of SCRM
Research gap 2	Robust and systematic tools for risk identification and assessment
Research gap 3	Application of total cost of ownership thinking to SCRM
Research gap 4	Further validation of SCRM concepts with empirical methodology

Firstly, the development of tools and supporting literature to measure the costs and benefits of the SCRM in monetary terms has been a constant idea for future research in the past literature reviews and other directive literature of the field (see e.g. Colicchia & Strozzi 2012, 414; Khan & Zsidisin 2012; Ho et al. 2015, 5061; Fan & Stevenson 2018, 222). Colicchia and Strozzi (2012, 414) identify a need to further explore the value of supply chain risk management by comparing the investment for supply chain risk management with risk impact and risk probability to support decision-making and to understand the value of resilience. Similarly, Ho et al. (2015, 5061) propose that further research quantifying the cost-benefit relationship of SCRM could attract more organizational focus to SCRM. In addition, even the International Supply Chain Risk Management (ISCRIM) network of researchers and practitioners considered '*performance metrics and measurement tools for assessing the impact of risk and the effectiveness of SCRM practices*' to be one of the nine key themes of future development of SCRM field (Khan & Zsidisin 2012, 18). Norrman and Jansson (2004, 434) conclude the main logic by proposing that supply chain risks should be approached a way that aims not to minimize risk but '*to find the efficient level of risk and prevention*'.

According to Tang (2006), especially problematic part of delivering the SCRM cost-benefit analysis to find the efficient means and level for risk management is to provide estimates of risk impact and risk probability due to lack of data. This might lead to underestimation of risk and inadequate resources allocated to risk management activities. Some authors further emphasize the importance of risk impact evaluation and high impact risk events to SCRM decision-making as it seems to resonate better to managerial mindset than risk probability low impact risk events (see e.g. Norrman & Jansson 2004, 446; Tang & Musa 2011, 26). These viewpoints lead to the second research gap of the thesis, development of further risk assessment tooling:

The need for further and more robust and systematic tooling for the first steps of SCRM process, identifying risks and assessing their impact, seem to arise from literature. Naturally, significant work on presenting different tools for these activities has been presented and same needs has been emphasized throughout the development of SCRM literature (see e.g. Jüttner et al. 2003; Norrman & Jansson 2004; Manuj & Mentzer 2008a; Ho et al. 2015). However, Colicchia and Strozzi (2012, 412, 414) emphasize the need for new tools risk identification and assessment and propose that they should be structured and systematic but also consider the interconnectedness of the supply chain risks and parties of the supply chain. The ISCRIM network also identified development of '*robust analytical tools and framework*' in general level of SCRM as of the key themes of future development of the field (Khan & Zsidisin 2012, 18). The importance of risk assessment and identification seem to emerge especially from the need of prioritizing risks to find the most significant risks to manage (Gaudenzi & Borghesi 2006, 114; Fan & Stevenson 2018, 215). Same need has also been recognized in the literature field of supply chain sustainability risk as Hajmohammad and Vachon (2016, 59) emphasize the importance of accurate risk assessments to utilize the resources of company effectively or avoid endangering its reputation.

Thirdly, to support the assessment of supply chain risk impact, the applications of influential concept presented by Ellram (1993a), total cost of ownership (TCO), has seen very limited application in the literature. Total cost of ownership thinking, that focuses especially on evaluating total cost implications of, for example, investment of supplier relationship, has been proposed to be combined with the concept of supply chain risk specially to support supplier selection processes (Rao & Goldsby 2009, 115–116). In addition, Zsidisin et al. (2000, 196) encouraged already in the beginning of the 2000s, to utilize total cost perspective into evaluating the impact of risk events. Furthermore, recently van Hoek (2020b) has been proposing the usage of TCO thinking to supply chain risks of Covid-19. In other study, van Hoek (2020a, 351–352) proposes extending the TCO model for SCRM usage with emphasis on flexibility related factors like response times. Thus, there seem to exist positive expectations on combining TCO and SCRM thinking despite the lack of existing applications.

Fourthly, from methodological perspective, utilization of empirical methodology has been overrun by more theoretical approaches creating a methodological gap in SCRM literature. According to Ho et al. (2015, 5060), methods and conceptual frameworks of SCRM literature has not been analyzed widely enough with empirical validation. Thus, more applications of existing concepts in practical settings are proposed. Furthermore, the need to investigate the approaches of practitioners and generate empirically based knowledge about tools and measurement systems to assess risk impact has been identified in the literature (Harland et al. 2003, 55; Colicchia & Strozzi 2012, 414). The importance of conducting the empirical research in different industry contexts is also emphasized by certain researchers (Jüttner et al. 2003; Fan & Stevenson 2018, 222).

1.2 Research questions

To provide managerial implications for the practical business issue of the Client and to offer research implications for the four identified research gaps, the aim of the study is to explore a method to assess the total cost of supply chain risk and test and develop the method in the context of the Client company. This objective is further generated into two research questions presented in this subchapter. The interrelations of four research gaps and two research questions are illustrated in Figure 1.

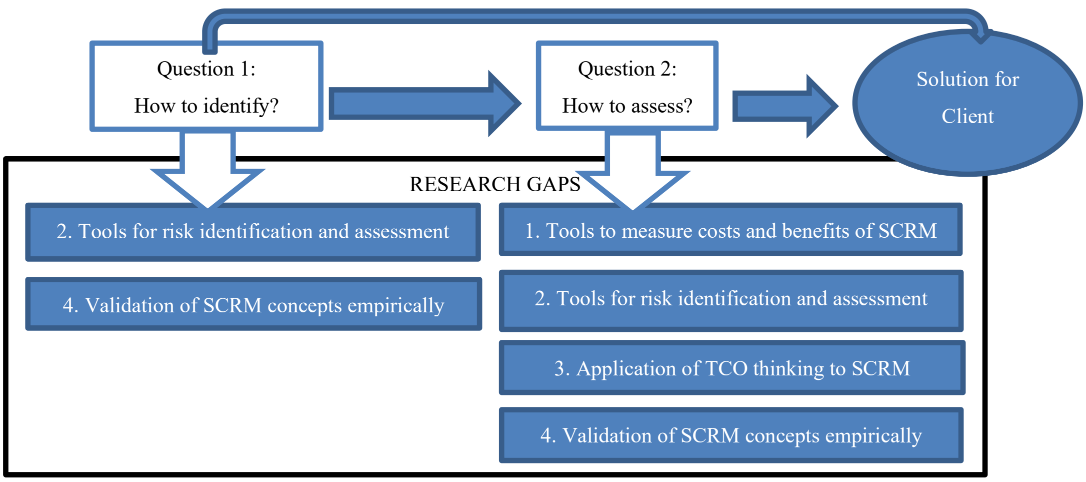

Figure 1. Interrelations of research questions, research gaps & practical solution.

Research question 1:

How can the supply chain risk impact be identified?

The first research question is utilized to provide tool to identify the risks and risk impacts in the supply chain. The research question is answered by reviewing the literature of supply chain risk management and creating construction 1 of supply chain risk and risk impact identification tool. Construction is then tested and further developed by applying it to the supply chains of Client. The research question contributes directly to research gaps 2 and 4 by providing tooling to support SCRM risk identification and applying the tooling into real-life supply chain analyses. Furthermore, in comparison with the generic SCRM processes utilized in the literature (see e.g. Zsidisin et al. 2005, 3405; Manuj & Mentzer 2008a, 143; Fan & Stevenson 2018, 208), the risk identification provides necessary foundation to assess or evaluate the risk impact and, thus, it indirectly enables the contribution to research gaps 1 and 3 and solution to practical issue of the Client.

Research question 2:

How can the total cost of supply chain risk impact be assessed?

The research question is used to create a tool to assess the total cost of supply chain risk impact. The question is answered by reviewing the literature of supply chain risk management and total cost of ownership and creating construction 2 of total cost of supply chain risk tool based on the risk and risk impact identification construction created by answering the research question 1. Construction is then tested and further developed by applying it to the supply chains of Client. The research question contributes directly to all the research gaps 1, 2, 3 and 4 by providing tooling to support cost-benefit analysis of SCRM, SCRM risk assessment and applying the total cost of ownership approach into supply chain risk assessment as well as applying the tooling into real-life supply chain analyses. The solution for the practical issue of the Client is supported by providing tooling for monetary supply chain risk assessment and providing insight about the analyzed supply chains for the Client.

1.3 Research design

1.3.1 Strategy

The overall research strategy is based on the *qualitative* and *constructive* research approaches. Furthermore, the study is divided into theoretical and empirical sections:

Firstly, in the theoretical section, to lay a theoretical background for the proposed tools or constructions for risk impact identification and total cost of risk assessment, the academic literature from the fields of supply chain risk management and the framework of total cost of ownership are reviewed and the constructions are formed based on the review. This section is mostly related to the preparatory phase of the research process of constructive research approach (CRA) by Lukka (2000). His model includes total of three phases: preparatory, fieldwork and theorizing.

Secondly, in the empirical section, the constructions are tested and further developed by utilizing the toolbox of single case study in the context of the Client company by utilizing three supply chains of the Client for background and testing. The outcome of this activity is the enhanced final construction combining both theoretically based constructions. This first half of the second section is closest to the fieldwork phase of the CRA research process (see Lukka 2000). Furthermore, the feedback generated in the testing is compared with the findings of the literature and the applicability of the construction including results of the weak market test is reviewed together with the limitations and ideas for future research. This latter half the empirical section contains the elements of the theorizing phase of the CRA research process (see Lukka 2000).

The general research strategy is inspired by the empirical study of supply chain risk management tooling provided by Canbolat et al. (2008) reviewing the area of monetary risk impact assessment as well. However, the TCO focus and CRA approach was lacking from the work of Canbolat et al. and the scope of their work was also including the risk management strategies more profoundly.

1.3.2 Scope

Few important boundaries are set for the scope of the study which expose the study to related limitations. Firstly, due to the needs of the Client and the nature of the master's thesis work, the study focuses on the first two steps of the generic SCRM process, risk identification and risk assessment, excluding the subsequent steps of risk mitigation and monitoring (see e.g. Zsidisin et al. 2005, 3405; Fan & Stevenson 2008, 208). In addition, the emphasis is more on the monetary assessment of the risk impact due to needs of the Client.

The justification of Hou and Zhao (2020) for the scope of the two first phases of the SCRM process is followed: They propose that the criticalness of the risk identification and assessment for the completeness and effectiveness of the rest of the SCRM process justify the focus in the two first steps. In addition, emphasis on risk impact in monetary terms is inspired by the proposals of the literature, that the assessment of risk impact especially in financial terms resonates more strongly to the practitioners than the assessment of risk probability (see e.g. Norrman & Jansson 2004, 446; Tang & Musa 2011, 26). This aspect is more closely discussed in the subchapter 3.1.2 reviewing the relationship of risk impact and risk probability.

However, the objective of holistic view to whole SCRM process including intangible and non-financial examination, will not be entirely captured by the study, and this might pose a limitation for the usability of the study (see Tang 2006, 482; Fan & Stevenson 2018, 215–216, 220). In addition, the Client being a non-listed subsidiary, the risk impact implications to shareholder value cannot be addressed comprehensively in the study.

Secondly, even though the aim of the study is not to produce an industry-specific construction, the by-product of the selection of the three supply chains of the Client – the industrial context of electronics and semiconductor industry as well as fulfilment of automotive customer needs – function as a background factor for the empirical study.

This approach is well aligned with the need recognized in the literature to enrich empiric SCRM studies with the context of the industry and to even create industry specific concepts (see e.g. Jüttner et al. 2003, 204–205; Khan & Zsidisin 2012, 18; Fan & Stevenson 2018; 222). However, this setting of scope exposes the study to inevitable limitation of generalization to other supply chain contexts and this task is assigned for the scope of the future research.

1.3.3 Structure

The structure of the research is organized, firstly, into three main chapters of the literature review which form the preparatory phase of the study (see Lukka 2000). That is followed by the presentation of methodology and analysis of the results which represent the fieldwork phase. Finally, discussion and conclusion of the findings of the study are reviewed which represent the theorizing phase of the study.

First main chapter, chapter 2, reviews the key concepts of supply chain risk and provides design principles for evaluating the two theoretically based constructions. Second main chapter, chapter 3, is focusing on addressing the identification of the risk and risk impact in the supply chain and, thus, contributes to the research question 1. Third main chapter, chapter 4, reviews the TCO concept, the cost components of risk impact and aims to compose a tool to assess the total cost of risk impact and similarly contributes to the research question 2. Chapter 5 presents and justifies the methodological selections of the study, reviews the detailed research process, and ponders research quality related aspects as well as ethical considerations. Chapter 6 analyses the results of the empirical study by presenting the final construction, supply chain risk analysis tool, developed based on the feedback received in Client company testing. Finally, chapter 7 concludes the main findings of the study, presents the theoretical contribution by comparing the results of the empirical study to the findings of the literature review based on the research gaps and theoretical proposals of the literature review as well as reviews managerial implications, future research ideas and limitations of the study originating from scope of applicability of the constructions.

2 MANAGING SUPPLY CHAIN RISK

In this first chapter of literature review, the focus is on chapter 2.1 on reviewing the concept of supply chain risk based on the academic literature of SCRM to lay the theoretical basis for the concept of supply chain risk in the constructions. In addition, on chapter 2.2 few design principles are reviewed to establish criteria for formulating and evaluating the constructions from the perspective of literature. In a summary, a solid foundation for the formulation of constructions is established.

2.1 Concept of supply chain risk

2.1.1 Key concepts

Supply chain risk management (SCRM)

The management of risk has been identified as one of the key activities of operations and supply chain management for multiple decades. For example, classic business strategy framework of Ghoshal (1987) distinguishes risk management as one of the three ultimate strategic objectives leading to competitive advantage of any organization. As another example, the classic supplier relationship framework of Kraljic (1983) utilizes supply market risk as one of the background elements of the extremely popular matrix model.

As the research and literature of supply chain risk in the research field of supply chain management has been advanced, numerous definitions for SCRM has been emerged (see Rao & Goldsby 2009, 196; Ho et al. 2015, 5036). Some of the earlier definitions presented by literature define the SCRM as the identification and management of risks and focus on the reduction of supply chain vulnerability or the collaboration-based process of SCRM (see e.g. Jüttner et al. 2003, 201; Norrman & Jansson 2004, 436). Deriving from two more recent and more comprehensive definitions of Fan and Stevenson (2018, 210) and of Manuj and Mentzer (2008b, 205), SCRM can be understood as follows: The steps of SCRM process include, firstly, identifying supply chain risks, secondly, assessing risk probability and related consequences or impact, thirdly, treatment of risks by implementing relevant strategies and, finally, monitoring the outcomes of the SCRM. The SCRM is supported by co-operation of the different parties of the supply chain and the aim is to ensure the profitability and competitive advantage of the whole supply chain rather than just one company via reducing supply chain costs and vulnerability to risk.

Supply chain risk (SCR)

According to the academic literature of supply chain risk management, basic concept of supply chain risk can be defined as distribution, variation, or uncertainty of outcomes for supply chain created by different risk events (Manuj & Mentzer 2008b, 197; Rao & Goldsby 2009, 100). According to the Manuj and Mentzer (2008b, 197), without risk created by risk events, the outcome of any activity would be known beforehand precisely.

The definitions of SCRM emphasize the supply chain risk as a concept related to outcomes for different performance measures of supply chain in negative or undesirable terms. These negative performance outcomes can be related to for example service levels, cost or incompatibility of supply and demand. (Jüttner et al. 2003, 200; Tummala & Schoenherr 2011, 474.) Thus, the unexpected positive outcome for supply chain – such as strengthening of relationship to supplier base or unexpected increase of supply chain profitability – is not understood to be created by supply chain risk according to many of the authors. In addition, Tang and Musa (2011, 26) select a narrower definition of supply chain risk: In their opinion, the negative outcomes created by risk events should be 'substantial' and the probability for the events 'small'.

Components of supply chain risk (SCR)

Common to the definitions of supply chain risk in general are the appearance of following components: losses, consequences or impact of risk, the significance of these consequences and the probability of the event leading to consequences (Manuj & Mentzer 2008a, 135). Thus, according to the Norrman and Jansson (2004, 436), in its most simple mathematical form the supply chain risk can be expressed as the product of probability of the event (P) and the business impact (I) of the event:

$$\text{Risk} = P * I$$

Thus, the basic components of supply chain risk are as follows: Firstly, *risk event* refers to an incident that triggers the distribution of supply chain outcomes. Example of such risk event could be for example supplier bankruptcy. (Manuj & Mentzer 2008b, 197, 201.) Secondly, *risk probability* refers to the likelihood that risk event happens (Manuj & Mentzer 2008a, 134–135). Thirdly, the risk can be understood as the *risk impact* or *risk* *consequences* which are the usually negative outcomes of realized risk event and their significance (Manuj & Mentzer 2008b, 196; Tang & Musa 2011, 26). The impact is usually expressed as a loss of a certain measure; for example, a loss in terms of financial, performance-related, or timewise measures (Cousins et al. 2004).

Especially, the relationship between the dimensions of probability and impact has been a center of discussion in multiple studies and it has been argued that risk impact is more significant component for practical SCRM decision-making related to prioritization than the risk probability (see March & Shapira 1987, 1407–1408; Mitchell 1995, 116–117; Cousins et al. 2004, 557–558; Norrman & Jansson 2004, 446).

In addition to components of event, probability, and impact, additional important components of supply chain risk are also presented by literature: Firstly, the *risk sources* are environmental variables that create the uncertainty to outcomes of supply chain operations. These sources can be internal to supply chain – for example emerging from process variation of suppliers – or external to supply chain – for example currency fluctuation, natural disasters, or diseases. (Jüttner et al. 2003, 199–200). The concepts of risk event and risk source seem to be partially overlapping. However, in this study the risk sources are meant to be referring to the taxonomy of different kind of sources for risk events: for example, demand fluctuation or supplier financial instability. In contrast, risk events are meant to be referring to the actual realization of risk source leading to risk impact: for example, rapid decrease in demand of one or multiple customers due to source of fluctuating demand or supplier bankruptcy due to source of financial instability.

Secondly, Manuj and Mentzer (2008b, 196–197) identify two additional components of supply chain risk which are proposed to be especially important related to global supply chain: speed of risk and frequency of risk. Firstly, *speed of risk* refers to the speed of risk event leading to risk impact – for example, the time between the supplier manufacturing disruption to lost sales to customer – and to speed of detection of the risk event which can for example refer to how quickly the supplier disruption is noticed or notified by supplier. Secondly, *frequency* measures the commonness of the risk event. In other words, as explained by authors: 'how often a similar kind of risk event happens'. On the contrary, Bandaly et al. (2012, 253) recite that the detection of risk event or failure is not relevant to the supply chain risks due to their significantly visible nature. This might be true with some of the acts of God like earthquakes. However, especially man-made disruptions like supplier shutdowns are usually known in advance by some parties of the supply chain so detection of risk is not excluded from the scope of this study.

In addition to the components of supply chain risk, concepts of uncertainty, supply chain vulnerability, and risk drivers are closely related to the nature of supply chain risk: *Uncertainty* can be defined as inability to determine probabilities or outcomes of certain event of decision and is sometimes utilized as a term interchangeably with risk. Uncertainties increase the supply chain risk and different kind of uncertainties might lead to supply chain risk to occur. However, unlike risk, uncertainty is something that cannot be measured or calculated. In addition, uncertainty does not necessarily lead to risky situation on negative impact. Thus, risk is measurable uncertainty that has potential consequences to supply chain. (Norrman & Jansson 2004, 436; Manuj & Mentzer 2008a; Sanchez-Rodrigues 2010, 46; Leat & Revoredo-Giha 2013, 220; Ghadge et al. 2017, 263.) For example, uncertainty of exchange rates might exist in the environment of the supply chain but might not expose it to risk if the transactions are done with single currency.

The concept of *supply chain vulnerability* is referring to supply chain's propensity of supply chain risk which overcomes the activities targeting to mitigate risk (Svensson 2002, 112; Jüttner et al. 2003, 201). This characteristic can also be expressed as lack of robustness which some authors propose to be determined by the weakest link of supply chain (Kleindorfer & Saad 2005, 55). For example, increased risk of hurricanes in the location of single capable supplier for critical component in the supply chain might increase the vulnerability of the supply chain and make it less robust.

Finally, the concept of *supply chain risk drivers* refers to factors in supply chains that increase the level of supply chain risk and thus supply chain vulnerability. These might include, for example, the increased complexity in supply chains due to trend towards globalized supply chains and outsourcing of activities. These drivers are usually created by intentional decision towards more efficient and profitable supply chain designs and can be thus understood to be 'calculated risk' in nature. (Svensson 2002, 119; Jüttner et al. 2003, 200, 205; Manuj & Mentzer 2008b, 213–214.)

According to Jüttner et al. (2003, 201), it is critical for managerial use of supply chain risk management to assess the *risk sources*, define the most relevant *risk impacts,* and track the *risk drivers* to mitigate the supply chain risks. Thus, in addition to the review of the supply chain risk impact, the risk drivers and risk sources are reviewed in the chapters 2.1.3 and 2.1.4 and they are considered to be considered in the construction.

2.1.2 Holistic approach & characteristics of supply chain risk

There are few distinctive characteristics related to the nature of supply chain risk proposed by the field of SCRM literature. Some of these characteristics might impact the applications of SCRM and, thus, they should be considered in the construction.

Firstly, the interconnectedness of the supply chain risks is a common theme mentioned by multiple studies of the SCRM field (see e.g. Chopra & Sodhi 2004, 54; Manuj & Mentzer 2008b, 198; Kwak et al. 2018, 373). Tang and Musa (2011, 29) explain that this interconnectedness happens as a product of connections between different flows of the supply chain and, thus, a disruption in one flow might affect the other flows as well. Example of such case might be for example disruption of one supplier leading to loss of sales to customers which, in turn, leads to payment issues to other supplier base which might lead to further disruptions. Chopra and Sodhi (2004, 54) add that measures targeting to mitigate one set of risks might increase vulnerability to other risks. Furthermore, Manuj and Mentzer (2008b, 198) emphasize that the magnitude and uncertainty of the impact of interconnectedness is even larger in supply chains with global footprint. Kwak et al. (2018, 373) conclude that analysis and modelling for supply chain risks should include these interactions of risks originating from different flows and stages of the chain.

Secondly, a fundamental characteristic of risk in general is the change (Ghoshal 1987). As an example from product life cycle level, the prototype development or engineering phase of a product can carry different risk implications than the subsequent production phase (Canbolat et al. 2008, 5153). In a more general level, the increasing importance of supply chain sustainability risk is an example of the change in supply chain risks created by external environment. The ability to identify changes in supply chain risk has also been identified in the development of SCRM tools (Blackhurst et al. 2008, 144).

Thirdly, in addition to the interconnectedness of different risks, the supply chain risk is very dynamic in nature when it appears in the supply chain context involving various parties in multiple tiers of chain. The risk of parties in the chain and activities related to them have direct effects to other parties in the chain. What is a risk outcome for one company – for example a bankruptcy – might be a severe risk event for other companies on the chain as well. (Chopra & Sodhi 2004, 54; Manuj & Mentzer 2008b, 201.) As another example, buffer created to handle variation in demand might lead to massive quality risk for downstream if there are unanticipated quality issues in the material of the buffer stock. Furthermore, the supply chain easily becomes amplified in the supply chain structures. In supply chain level, classic example of this amplification is the bullwhip effect – massive fluctuations in demand, inventories and lead time driven by lack of visibility in the chain (Wu et al. 2007, 1666). As another example, this amplification can occur when the supply disruption of one component with low price per piece leads to losses of hundreds of thousands of euros (Canbolat et al 2008, 5146). Dynamic nature of risk in chains might also be exaggerated by different position of parties of chain towards supply chain risk: Vilko and Hallikas (2012, 586) propose that the supply chain risk and SCRM activities are strongly dependent on the company position in the supply chain and their capabilities related to risk analysis.

The mentioned characteristics – interconnectedness of risks, change and dynamic nature in supply chain structures – lead to a demand of holistic perspective in tools and constructions related to supply chain risk. This holistic perspective has been identified by numerous authors of the field: Manuj and Mentzer (2008a, 133) emphasize the importance of considering entire supply chain including all countries and parties of the chain in the SCRM activities. Rao and Goldsby (2009, 101, 115) add that the SCRM activities should pursue solutions that improve outcome for the entire supply chain – not just the outcome for the focal company. In addition, they add from functional perspective that including the impact of risk to wider scope of functions related to the supply chain – including for example, marketing, sales and research and development – is essential to identifying supply chain risks. Vilko and Hallikas (2012, 593) as well as Kwak et al. (2018, 375) identify the need for holistic understanding of supply chain risk and structures including the relations and hierarchies between risks.

Inspired by these viewpoints, the holistic or comprehensive approach to identifying and assessing supply chain risk impact in terms of supply chain structures and risk concept is in the interest of the constructions. In addition, the principles of TCO thinking might support this approach by holistic or 'total' perspective to cost (see e.g. Rao & Goldsby 2009, 115–116).

2.1.3 Drivers of supply chain risk

As discussed, the supply chain risk drivers are factors that increase the vulnerability of the supply chain and impact of supply chain risk. The risks drivers are usually generated by decisions to achieve other goals in supply chains, for example efficiency, and thus can be understood as calculated risk in nature. (Svensson 2002, 119; Jüttner et al. 2003, 200, 205; Manuj & Mentzer 2008b, 213–214.). Identification of the risk drivers in the supply chain can elaborate on the success of the managerial use of SCRM so the evaluation and they have effect on the severity of risk impact (Jüttner et al. 2003, 200–201). Thus, considering the risk drivers in the supply chain risk impact constructions of this study might elaborate to answering the research questions as well as support the holistic approach to risk concept. Next, significant risk drivers increasing supply chain vulnerability proposed in the literature, are presented:

Firstly, the *complexity* in supply chains has been creating additional risk to supply chain due to trends of outsourcing and extending global footprint of supply chains. (Jüttner et al. 2003, 205). In addition, in the complex and global supply chains, the parties of the supply chain face the challenge of coordinating activities with vast number of partners in multiple different locations (Yeung 2007, 4). Manuj and Mentzer (2008b, 213–214) has collected the following dimensions of complexity from the work of different authors of literature: tiers of the supply chain, technology, processed of information, amount of logistics transactions, stock keeping units, number of partners, number of countries and combinations of origins and destinations.

Secondly, due to the outsourcing of operations, reduction of supplier base and advantages of IT in supply chains, the parties of the supply chains are more and more *integrated*. This development has also increased the exposure to risk due to lack of ownership between parties and the increasing speed of risk impacts flowing through an integrated chain. (Jüttner et al. 2003, 205; Hendricks & Singhal 2005b, 50-51; Durowoju et al. 2012, 1002.) However, the integration of supply chains can also moderate the impact of supply chain risk, if it leads to collaborative sharing of information increasing visibility or inter-organizational learning (Kleindorfer & Saad 2005; Manuj & Mentzer 2008b, 213–214).

Thirdly, according to Christopher and Lee (2004, 389–390) *lack of confidence* between the parties of supply chain enforced by the *lack of visibility* and *lack of control* between the supply chain partners create a chain of events called '*risk spiral*' which increases supply chains exposure to risk. Without visibility to total stock and capacity and its locations throughout the supply chain, the parties of the chain lose their confidence to total stock situation and are forced to increase inventory buffers in their operations. This in turn, sends wrong signals to upstream of supply chain which decreases visibility further. The risk spiral is further amplified if the parties of supply chain are lacking control over the supply chain activities: for example, due to long lead times, it takes a long time to implement changes in supply chain to respond emerging risks even if the visibility to chain would be adequate. The concept of risk spiral seems to be closely related to the concept of bullwhip. Real business example including occurring of risk spiral is provided by Chopra and Sodhi (2004, 56) who report that disruptions in supply led the customers of Nokia order over their needs due to lack of confidence and visibility to availability which, in turn, provided unrealistic demand information to Nokia. In turn, Lorentz and Hilmola (2012, 348) identify the confidence in supply chain to moderate the interconnection of risk impact and adjustments to supply chains implemented. Furthermore, due to occurrence of risk spiral, holistic approach to risk structures is proposed by Kwak et al. (2018, 375) as well.

Fourthly, the *lack of slack* or flexibility in terms of capacity, inventories, and human resources in modern supply chains due to more lean and efficient supply chains may increase the vulnerability of the supply chain as there is less buffer to absorb the impact of risk events (Hendricks & Singhal 2005b, 50–51; Kleindorfer & Saad 2005, 55; Knemeyer et al. 2009, 141). As one type of the lack of flexibility, dependability to reduced number of suppliers might increase the vulnerability of the supply chain if, for example, the single supplier faces severe disruption in its operations (Hendricks & Singhal 2005b, 50–51). This kind of risk exposure might happen due to limited number of capable suppliers, called technological exposure, or from decision to reduce supplier base to single source, called strategic exposure (Cousins et al. 2004, 556). The most famous business case related to this issue happened in 2000, as Ericsson's single suppliers for a certain microchip was unable to supply due to its clean rooms were damaged due to fire created by lightning strike. This led to losses of several hundreds of millions of dollars as lost sales for Ericsson. (Chopra & Sodhi 2004, 53; Norrman & Jansson 2004, 441.) More recently, the significance of flexibility in supply chain decision making has been highlighted recently by van Hoek (2020a, 351) due to effects of Covid-19.

In addition to the drivers related to the supply chain design, the supply chain risk might be driven by the *perception of risk* at supply chain and its parties. According to Liu and Nagurney (2011, 548), some companies might be more neutral to risk, being less sensitive to higher risk of decisions, and other more risk-averse, being more concerned about risk. In addition, due to the lack of adequately accurate estimates for supply risks, the companies tend to underestimate the risk which might lead to insufficient countermeasures (Tang 2006, 479–480). Furthermore, the commitment of the executives to supply chain risk management and performance targets of managers seem to affect how the risk is perceived, prioritized, and managed according to the findings of literature (Zsidisin et al. 2000, 195–196; Tang 2006 479–480; Manuj & Mentzer 2008b, 204).

2.1.4 Risk source taxonomies

As discussed, in addition to the risk impact and probability, third important component of supply chain risk, risk sources, has been identified as one of the key objects for identification in SCRM process (Jüttner et al. 2003, 201; Bandaly et al. 2012, 253). Risk sources are usually organized as certain taxonomies as per source type or categories in the studies and wide number of different taxonomies exist in the literature (see Ho et al. 2015, 5037). According to Wu et al. (2006, 351), the risk classifications or taxonomies support the identification and prioritization of risk groups that expose the supply chain to risk most severely. Thus, some of the different taxonomies are discussed in this chapter to create a basis for utilization of risk sources as supporting factors for supply chain risk and risk impact identification tool formulized.

Kleindorfer and Saad (2005, 53) provide a broad taxonomy based on whether the risks are arising from issues in coordination of supply and demand, or they are disruptions to normal operations. Similar kind of taxonomies are provided by several authors who, firstly, identify ‘micro risks’ or ‘operational risks’ which are more recurrent and inherent uncertainties including demand, cost and yield emerging from within the companies of the supply chain or from their relationships and, secondly, ‘macro’ or ‘disruption risks’ which are more adverse and infrequent emerging from external environment of supply chain, for example natural disasters, political instability or economic crises (Tang 2006, 453, 457; Vanany et al. 2009, 17; Ho et al. 2015, 5052–5053).

Furthermore, many popular taxonomies of risk sources classify the risks based on the position in comparison with the focal company: ‘Supply risks’ originate from the supplier base and include for example supplier opportunism and inbound product quality. ‘Demand risks’ are based on the customer base and include for example demand variation and forecast errors. ‘Operational risks’ emerge inside the operations of company and include for example inventory ownership and changes in technology. ‘Other risks’ or ‘environmental risk’ are close to the ‘macro risks’ and originate from the external environment, for example economic instability, currency fluctuations and security. (Manuj & Mentzer 2008a, 138–139; Manuj & Mentzer 2008b, 197–198, 201; Hou & Zhao 2020).

These taxonomies are in general level, but they might provide interesting insight to risk impact assessment. Firstly, disruption risks seem to provide more remarkable impact for supply chain but less frequently than coordination risks which might provide preliminary direction for assessment of risk impact. Secondly, the classification of risk based on their source from inside the supply chain, focal company or from external environment also reflects their controllability as supply chain parties usually have more control over their internal than external environment (Kwak et al. 2018, 374). Wu et al. (2006, 351–353) also emphasize the importance of evaluating the controllability of different kind of risk sources from other internal and external risk sources. Furthermore, from risk assessment perspective, Manuj and Mentzer (2008a, 136–137) divide risk sources to atomistic risks which require only limited part of the supply chain for assessment due to non-complex nature and holistic risks which require entire supply chain analysis due to their complex and unique nature potentially effecting the whole supply chain. These approaches are closely related to the lack of control as driver for supply chain risk leading to potentially higher risk impact for risk sources which are less controllable for focal company or other party of the supply chain (see Christopher & Lee 2004, 389–390).

In addition to the classifications related to the parties and environment of the supply chain, some taxonomies classify the supply chain risks based on the related flow in the supply chain. These flows are usually classified to, firstly, *material flow* including risks related to for example operational disruptions, demand variation and inventories, secondly, *information flow* related to for example information accessibility and accuracy of data, and, thirdly, to *financial flow* including exchange rates, financial position of parties of the supply chain. (Tang & Musa 2011; Hou & Zhao 2020). In addition, supply chain or supplier sustainability risk discussed by for example Hajmohammad and Vachon (2016) might be additional 'flow' to consider in the taxonomy. These risk source taxonomies provide interesting link to risk impact identification, as many of the classifications and taxonomies of the risk impact are based on similar kind of types, including financial loss, physical loss, or time loss, as well (see e.g. Mitchell 1995, 115; Harland et al. 2003, 59; Vilko & Hallikas 2012, 590–592; Kwak et al. 2018, 375). Thus, these risk taxonomies could be used to support the bridge between the relevant risk sources and subsequent set of risk impact.

Table 2. Risk categorization logic based on source and controllability of risks (based on Blackhurst et al. 2008, 149).

Category of risk	Internal risks (controllable)	External risks (limited or no control)
Disruptions/disasters	Labor dispute …	Supplier bankruptcy …
Logistics	On-time delivery to customers …	Border crossing and customs regulations …
…	…	…

In addition to the differences in impact magnitude, frequency, and controllability of internal and external risk sources as well as utilization of supply chain flow-based classification of risk sources as a bridge to types of risk impact, context-specificity of risk sources is a third aspect to consider in the risk impact identification construction related to the risk sources. Wu et al. (2006, 351) notice that a classification system for risk can be chain independent or more tailored to specific supply chain context. Blackhurst et al. (2008, 148–149) propose that a company should formulate the risk categories based on for example their needs, industry, and supply chain design. As another interesting contribution, they provide a risk categorization for automotive manufacturer which might be found relevant for this research due to the strong automotive industry emphasis of the case company. In addition, their categorization combines the risk source categorization to the controllability of the risks. Example of the logic is presented in Table 2.

2.2 Design principles for SCRM constructions

The academic literature of SCRM offers multiple principles and conditions for SCRM approach and tools to take place in successful manner. These propositions are synthesized into 5 design principles for the constructions of the thesis to guide their formulation and to establish criteria to evaluate the constructions from the perspective of academic literature. The five design principles are summarized in table 3:

Table 3. Design principles for SCRM constructions with related literature.

Design principle 1	**Holistic and comprehensive approach** to supply chain risk is applied.	Ghoshal (1987) Chopra & Sodhi (2004) Neiger et al. (2009) Tang & Musa (2011) Vilko & Hallikas (2012) Kwak et al. (2018)
Design principle 2	**Quantification** and measurement with business-oriented manner is applied.	Applequist et al. (2000) Rice & Caniato (2003) Kleindorfer & Saad (2005) Canbolat et al. (2008) Neiger et al. (2009)
Design principle 3	**Proactive approach** is established supported by lessons learned of the past.	Rice & Caniato (2003) Kleindorfer & Saad (2005) Canbolat et al. (2008) Norrman & Wieland (2020)
Design principle 4	**Cross-organizational and cross-functional** approach is applied without forgetting one's own responsibility of common targets	Applequist et al. (2000) Rice & Caniato (2003) Kleindorfer & Saad (2005) Canbolat et al. (2008) Neiger et al. (2009)
Design principle 5	**Industrial context** is utilized but the aplicability is not bound to it	Kleindorfer & Saad (2005) Vanany et al. (2009)

Main frameworks utilized for the design principles are especially list of 10 principles of risk management presented by Kleindorfer and Saad (2005, 55), summary of 7 desirable properties focusing on SCRM identification by Neiger et al. (2009, 156) and SCRM maturity model of Rice and Caniato (2003, 27).

Design principle 1:

Holistic and comprehensive approach to supply chain risk is applied.

First design principle was already generated in the chapter 2.1.2 based on multifacetedness of different supply chain risk components and interconnected, change-sensitive, and dynamic nature of risk in supply chain structures. Thus, holistic approach related to risk components, dynamics and scope of included supply chain parties is applied as the first design principle for SCRM constructions. One implication of the design principle is including the risk sources and risk drivers as supporting factors for the supply chain risk and risk impact identification tool construction. The approach is supported by desirable properties framework of Neiger et al. (2009, 156) who propose linking the SCRM identification into different functions of supply chain, risk sources and flows between organizations.

Design principle 2:

Quantification and measurement with business-oriented manner is applied.

Second design principle is related to the quantification of risks. Neiger et al. (2009, 156) propose as desirable properties for SCRM identification the quantification of risks for risk analysis and risk management approach evaluation as well as binding the risk analysis to business objectives and performance indicators. Applequist et al. (2000) support this connection of SCRM to business-connected measures by stressing the importance of evaluating supply chain and supply chain risk related investments with same kind of criteria than what is applied to other usage of capital. Kleindorfer and Saad (2005, 55), highlight the importance of evaluating trade-off between supply chain efficiency and supply chain robustness against vulnerability in their SCRM principle framework. They add that combining risk quantification and SCRM approaches to find the best cost-benefit of SCRM is of the utmost importance. In addition, the maturity model of Rice and Caniato (2003, 27) link the structured assessment and quantification of cost and benefit to highest levels of risk management maturity. More illustratively, Canbolat et al. (2008, 5162) encourage managers to avoid using 'gut feel' for balancing savings with risk and Kleindorfer and Saad (2005, 66) emphasize how the '*random investments and shots in the dark*' are detrimental to efficient use of resources and sustaining trust in supply chains.

Design principle 3:

Proactive approach is established supported by lessons learned of the past.

Kleindorfer and Saad (2005, 55) argue that the efforts conducted for risk management before the adverse risk event provide more value than efforts conducted to manage an already happened risk. In other words: 'prevention is better than the cure'. Thus, they propose that risk assessment, quantification and selection of adequate risk management strategies is important to conduct 'ex ante' rather than 'ex post'. Norrman and Wieland (2020, 642, 661) differentiate these approaches to proactive and reactive SCRM. They demonstrate how the severe risk events usually underline the importance of proactive approach and usually trigger the development of proactive means – a logic very distinctive in the Case Ericsson as they point out (see Norrman & Jansson 2004). Canbolat et al. (2008, 5152) also prove the interest for the proactive approach from the managerial world as their case company, Ford Motor Company, is eager to use proactive risk management approaches to foresee and mitigate the impact. Despite the importance of proactive approach, the reactivity is also important according to the Norrman and Wieland (2020, 642). Furthermore, the maturity model of Rice and Caniato (2003, 27) present that more mature organizations learn from the past to develop the SCRM approach.

Design principle 4:

Cross-organizational and cross-functional approach is applied without forgetting one's own responsibility of common targets.

Kleindorfer and Saad (2005, 66) propose that SCRM activities cannot be implemented in a void: collaboration and coordination and fair share of benefits between supply chain entities are needed for managing risks. In addition, they find increased visibility through sharing of information and best ways of working essential (see also Neiger et al. 2009, 156). According to them, the supply chain is as vulnerable as its 'weakest link'. Applequist et al. (2000, 2212) emphasize the importance of coordination in supply chain level as decision-making of supply chain partners is usually decentralized and not synchronized in time or objectives but interconnected. Rice and Caniato (2003, 27) also report that supply chain with higher SCRM maturity collaborate with each other in the forms of, for example, flexible contracts and joint risk management plans. In addition, they state that participation in the formulation of industry-wide standards and policies implicate higher maturity. However, Canbolat et al. (2008, 5162) add that SCRM decision-making is not just cross-organizational but also cross-functional process. Thus, they include the identified risks, objectives, and concerns from different functions of the organization in their SCRM model.

Despite the importance of collaboration, Kleindorfer and Saad (2005, 55) strongly argue that each party must manage the risks themselves before expecting or requiring others on the chain to do so and raise this as the first principle of risk management. On the contrary, it could be argued that is it possible to take this approach into SCRM efficiently before forming collaborative risk management relationships.

Design principle 5:

Industrial context is utilized but the applicability is not bound to it.

Especially Kleindorfer and Saad (2005, 59, 66), discuss the importance of context to SCRM. On the one hand, they propose that SCRM approaches should fit the characteristics of the industry, supply chain, and focal company. In the area of SCRM research, they also identify the importance of industry-specific knowledge in development of the research field. Furthermore, Vanany et al. (2009, 24) support this view by encouraging identifying typical risks of the industries in the future research. On the other hand, Kleindorfer and Saad (2005, 59) highlight the significance of generalizable SCRM approaches and theory for the '*general development of the field*'. From managerial perspective, the relevance of this viewpoint can be connected to the fact that certain supply chains might support customers and technologies from multiple industries, or the strategic industry-focus of the supply chain might change during the life cycle of the supply chain approaches.

3 SUPPLY CHAIN RISK IMPACT IDENTIFICATION

In this second chapter of literature review, the focus is on developing theoretically based construction for supply chain risk and risk impact identification to enable answering the research question 1, to enable assessment of total cost of risk on chapter 3, and finally to enable the risk impact identification in the empirical study.

To achieve this outcome, firstly, on chapter 3.1 the definition, drivers, and taxonomies of supply chain risk impact are presented to define the concept of risk impact in the construction. Secondly, on chapter 3.2 based on the most relevant toolbox for supply chain risk impact identification and initial analysis, construction for supply chain risk and risk impact identification tool is created.

3.1 Concept of supply chain risk impact

3.1.1 Definition & importance

Risk impact, which is sometimes referred as risk consequence as well, is the outcome of the potential risk and variance which have turned into realized risk event. The risk impact can occur in various forms, including monetary and quality impact. (Jüttner et al. 2003, 199–200.) One simple example of risk impact would be monetary impact of lost sales due to disruption in material supply, which has been discovered by for example Norrman and Jansson (2004) in their popular case study concerning Ericsson.

Knemeyer et al. (2009, 148–149) propose that measuring the risk impact of supply chain risk provides first and foremost a cross-functional understanding of risk consequences and the risk environment for management and supply chain locations. Thus, the formulation of risk mitigation strategies is supported. This, in turn, can be connected to the main purpose of risk identification and assessment proposed by Kwak et al. (2018, 383): decision-making about priorities for risk management. Tuncel and Alpan (2010, 257) explain this need of prioritization with the scarcity of resources and add that similar results can be achieved with priority-based and focused than more overall approach.

In addition to the need for prioritization, the importance of understanding the risk impact is related to the overall justification of supply chain risk management. Hendricks and Singhal (2005b, 36) propose that if evidence about the impact of infrequent and hard to predict but adverse events can be presented, justification for the resources allocated for managing the risk can be provided. Furthermore, Chopra and Sodhi (2004, 56) emphasize the importance of risk mitigation without risking profits and that this requires in-depth understanding of both risk and means for mitigation. Pettit et al. (2010; 2013) continue from this way of thinking and present the concept of 'balanced resilience' (see Figure 2). The idea is that too high level of SCRM capabilities leads to decreasing profits and too low level to extensive exposure or impact of risk. Thus, the optimum can be found somewhere in between and higher risk impact in the environment leads to higher level of required capabilities. To justify this right level of SCRM activities, similarly as Hendricks and Singhal (2005b, 36), Rice and Caniato (2003) state that SCRM activities require the business case behind them for justification and this case has the most effect when the risk impacts are quantified to describe the monetary extent of losses that are avoided. Similar kind of ideas have been presented by other authors as well (see e.g. Hendricks and Singhal 2005b, 50–51; Kleindorder & Saad 2005, 55, 66).

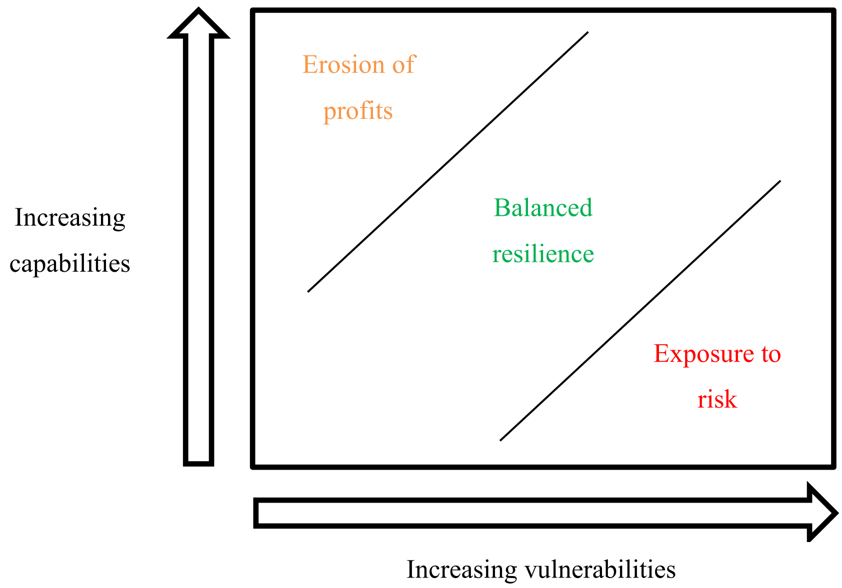

Figure 2. Balanced resilience (Pettit et al. 2010; 2013).

To conclude, measuring the impact is found to be 'essential' part of the SCRM process by literature and this should be done with a quantification and measurement system that is mutually agreed (Harland et al. 2003, 52–53; Kleindorfer & Saad 2005, 56; Bandaly et al. 2012). Despite the importance of the activity, the risk impact is found to be difficult to quantify in the literature – especially in financial terms. Knemeyer et al. (2009, 148–149) highlight that some of the risk impact items are more straightforward to measure than others. According to them, especially difficult are items including stockouts of loss of sales that include lots of intangible aspects. In contrast, Harland et al. (2003, 53) propose that risk impacts related to non-compliance of regulations can be estimated highly accurately due to known penalty cases.

3.1.2 Connection to risk probability

The relationship of the risk impact and risk probability, the two of the main components of supply chain risk, seem to have been discussed widely by the literature of SCRM. Some authors emphasize the importance of risk probability together with risk impact, but other highlight the importance of risk impact to be higher than the risk probability especially from managerial point of view.

Rao and Goldsby (2009, 99) describe the development of risk management literature through the portfolio model, where uncertainty creates variance for the reward. This approach originates from investment literature, but it has seen usage in the SCRM literature later as well. It seems, that this approach handles the impact and probability quite equally due to its mathematical nature including both components to equation. Furthermore, Zsidisin et al. (2004, 397) propose that perception of existing risk is generated through the presence of high probability for event with high impact. Thus, they highlight the importance of both components so that both higher likelihood and higher consequence increase the risk linearly.

However, the importance of risk impact to the perception of risk has been emphasized by multiple authors from different perspectives: Firstly, Manuj and Mentzer (2008a, 140) identify differences in the perceived and realized risk probability. On one hand, they note that high impact events happen more likely than usually estimated. On the other hand, they state that events with high perceived likelihood happen less likely than estimated. Thus, it could be understood that there is systematic inaccuracy in estimating the risk probability. Secondly, Knemeyer et al. (2009, 141) and Chopra and Sodhi (2004, 54) emphasize the importance of prioritizing the proactive risk management for risks with low perceived probability but high impact due to less slack in modern supply chains (see also 2.1.2). This viewpoint can be supported by the findings of Manuj and Mentzer (2008a, 140) as these high-impact, low-probability risks are more probable than is maybe estimated. Thirdly, March and Shapira (1987, 1407–1408) note that managers tend to consider the risk impact more important than the risk probability. This approach as well is supported by the classic case about Ericsson by Norrman and Jansson (2004, 446). They note that the likelihood of the risk is hard to estimate, and it is not understood clearly by people responsible of business decisions. Thus, they observe that Ericsson focuses on risk impact when prioritizing risks and risk sources.

Due to the importance of considering high impact risks regardless of the usually inaccurate probability level that is difficult to estimate accurately, and due to the managerial relevance of the risk impact estimation, the formulation of the constructions is based on a this theoretically based hypothesis that risk impact is perceived more important component than the risk probability. Thus, the constructions focus on risk impact rather than probability evaluation. This approach is also strongly supporting to the monetary focus of the constructions desired by the Client.

3.1.3 Drivers of risk impact

Likelihood, significance, and type of risk impact are influenced by multiple drivers identified in the academic literature. The list of drivers mentioned below is hardly comprehensive, but it provides important factors to consider in the risk impact analysis:

Firstly, company and supply chain might have different extent of influence on the risk. Some more powerful and large companies and organization might have lots of influence on their risk environment if they are, for example, able to strongly influence on the actions of supplier and customer base or legislative environment. In contrast, smaller and less powerful entities might not be able to do much else than react to realized risks of risk environment without much ability to control them. (Harland et al. 2003.)

The amount of influence seems to be related to the second driver: size of the company. Hendricks and Singhal (2005a) find that smaller firms suffer greater financial impact from supply chain risks. According to their study, the differences in the impacts for smaller versus larger firms is remarkable and statistically significant in the measures of operating income, return on sales and return on assets. Thus, it seems that smaller the company is, less it can influence the risk, and more it is exposed to the consequences.

Thirdly, the environment the company is operating naturally has wide influence on the risk impact. For example, as Harland et al. (2003, 53) note that the risks of non-compliance can be estimated quite accurately due to known consequences, the legislative and regulatory environment surrounding the entities of the supply chain have impact into this impact. An example of this logic might be for example selection of countries for supply chain presence based on how beneficial the tax environment and labour legislation. Furthermore, the environment might affect the harmful publicity of realized risk events which might be more severe for local companies in local environment (Harland et al. 2003, 52–53; Manuj & Mentzer 2008a, 135). In addition to the external environment, the dynamics of the supply chain environment might have magnifying or degenerative effect on the risk impact as the risk impact flows through the chain. The former is called a ripple effect which occurs in for example bullwhip effect and the latter is called a trickle-down effect. (Durowoju et al 2012, 1003). This dynamic nature of impact might be an important aspect when the consequences for the entire supply chain are considered.

Fourthly, the risk impact is driven by time. Hendricks and Singhal (2005a, 695) note that the negative financial impact from risk events continues for few years after the incident. Thus, the companies affected do not rebound back to their normal performance quickly. This influence is identified on operating income, sales, total costs, and inventories. Another very relevant time related driver has been proposed by Canbolat et al. (2008). They focus on different consequences of risk based on whether they occur in the prototype development or production stage of the product life cycle. In prototype development, the risk impact is most severely related to the delays in the launch and ramp-up of the developed solution. In production stage, the risk impact can, for example, be production disruptions and premiums paid due to related delays. Interesting connection of these time-intense drivers can be made to time-aspect of TCO thinking.

In summary, these drivers seem to provide important additional factors for the risk impact constructions. It seems that the sphere of influence of the entities of the chain and their size must be included in the analysis. In addition, the identification of risk impact and supporting risk sources must cover the external environment and the dynamic behavior of the risk impact flowing through the chain. Finally, considering the changes and development over time of risk impact and life cycle of the product seem to be beneficial for the constructions and support the application of TCO thinking on construction 2. All these drivers seem to support the holistic approach to risk discussed. However, it should also be noted that despite the magnifying effect of different risk drivers, Hendricks and Singhal (2005a, 695) identify negative impact to performance of some extent from the risk events regardless of, for example, risk source and industrial environment.

3.1.4 Risk impact taxonomy

Similarly, as with the risk sources, the academic literature of the SCRM field has provided taxonomies to support the classification of different types of risk impacts usually called ‘losses’ in this context. To support the identification and evaluation of the risk impact, the risk impact classifications based on the aspects of measurability, stressed business measure or resource and stressed party are presented.

Harland et al. (2003, 52–53) propose that risk might have tangible and usually financial impacts but also intangible impacts and both aspects should be included in the risk assessment. Likewise, Manuj and Mentzer (2008a, 135, 137) dually divide the risk consequences to quantitative impact including for example loss of sales and to qualitative impact including negative impact to brand or relationships to other businesses. These simple classifications might be relevant aspect for the risk impact constructions as the total cost of risk construction requires certain level of quantification of impact and the more tangible and quantitative nature of impact might support this construction with simpler quantification. Logic of Knemeyer et al. (2009, 148–149) seem to support emphasis of quantifiable impact: They suggest that the risk analysis should be started with more measurable impact items and the more qualitative items should be adjusted if they are found remarkable for the total impact. However, it should be noted that the connection of quantitative and financial nature of impact with quantifiability is not straightforward. For example, loss of sales is identified as quantitative by Manuj and Mentzer (2008a, 135) but also identified quite challenging to quantify by Knemeyer et al. (2009, 148–149) due to intangible components included.

The classical taxonomy of losses faced in procurement and further in supply chain context has been proposed as early as in 1970s by Jacoby and Kaplan as well as Roselius (Mitchell 1995, 115; Cousins et al. 2004). The taxonomy is based on the loss of business measure or resource of the business entity and thus seem to be related to the classical resource-based view of the company (see e.g. Barney et al. 2001, 625). In the taxonomy, the losses are classified into six types: financial, performance, physical, social, psychological and time (Mitchell 1995, 115). The taxonomy seems to be originally from the perspective of a single focal company but based on the modern view of competitive advantage acquired by managing risk in supply chains, the approach might be applicable as well to supply chain context (see e.g. Colicchia & Strozzi 2012, 210; Fan & Stevenson 2018, 403). Example is provided by, for example, Harland et al. (2003) in supply network context. Modern taxonomies used in the literature seem to provide classifications of losses based on the flows of the supply chain including material, financial, information and time or on the key measures of supply chain success including time, financial measures, and quality (Vilko & Hallikas 2012, 590–592; Kwak et al. 2018, 375). In addition, the environmental loss has been proposed as one type of risk impact (Cousins et al. 2004, 556).

Driven by the identified holistic nature of the SCRM context, the six classical categories of impact, financial, performance, physical, social, psychological and time, as well as three later additions of information, quality and environmental loss are included in a closer consideration below. The measurability of losses is important on reviewing which losses are critical especially for total cost of risk construction and which are more supportive in nature. It is worth noting that the categories are partly overlapping and highly interconnected: quality can be understood as performance measure and most of the impact might have indirect financial implications.

Firstly, the *financial* impact of risk is mentioned by most of the studies of the literature covering different types of risk impact (see e.g. Cousins et al. 2004; Blackhurst et al. 2008, Bandaly et al. 2012). The financial impact can happen in more accounting-based financial measures like loss in returns or in more strategic level in for example market share (Bandaly et al. 2012, 253). Hendricks & Singhal (2005a, 696) provide a comprehensible sub-taxonomy for financial risk impact: the impact might be related to revenue via sales and revenue via costs. The revenue impact via sales can take a form of lost market share and sales, sales price reduction and loss of net sales. These are partly driven by more social losses of customer dissatisfaction and lost reputation. The cost side of the revenue impact might be generated by inventory markdowns, cost of expediting, additional marketing costs, higher cost of capital and penalties. Risk might also have effect on insurance risk premiums of the companies of the chain or on the non-payments between entities (Norrman & Jansson 2004, 452; Leat & Revoredo-Giha 2013, 223). Studies of Hendricks & Singhal (2005a, 695; 2005b, 35) have identified lower growth of sales by 7 % and higher costs of around 11 % in companies that have faced supply chain risks. In addition, the negative effect on stock price and shareholder value has been identified to be about 10 % during the day before and during the risk event announcement.

As for practical examples of financial risk impact, classical cases include inventory markdown of over 2 billion dollars by Cisco in 2001 due to reduced demand, lost sales of 100 million dollars of Nike in 2001 due to product shortages and failed planning and the loss of sales by 400 million USD and business interruption cost of 200 million USD by Ericsson also in 2001 due to shortage of critical components from supplier facing a fire in clean room facility (Norrman & Jansson 2004, 435, 441; Christopher & Lee, 2004, 391–392). For a future example, it has been forecasted, that automotive companies might lose sales of 60 billion USD during 2021 due to component shortages (Bloomberg.com 7.4.2021).

To conclude, the financial impacts of risks seem to be potentially significant for companies and include the revenue implications via sales and costs as well as the impact on shareholder value. It can be argued that due to the nature of financial activities and rich set of empiric examples of literature with numerical loss values, the direct and indirect financial impact of risk should be more quantifiable and quantitative. In addition, due to the cost focus of TCO-based total cost of risk construction, the financial impact of risk is naturally in the very core of the analysis.

Secondly, the *loss of performance* generated by supply chain risk might include forced usage of inferior technology, reduction on service level and process performance as well as poor asset and inventory performance (Cousins et al. 2004, Hendricks & Singhal 2005a, 696; Tummala & Schoenherr 2011, 476). Quality and time-related impacts of risk are partially overlapping with performance and can be seen as subcategories of performance loss, but they are discussed separately in this chapter to gain wider consideration. Hendricks & Singhal (2005a, 695) identified inventory growth to be almost 14 % higher in the companies facing supply chain disruption. The lack of inventory performance throughout the supply chain can also be seen in the case of Cisco (Christopher & Lee 2004, 391–392).

Thirdly, the *physical loss* represents the negative impact on the physical resources of the supply chain or external environment. These losses include the damage to property and equipment but also public infrastructure like ports and roads (Helferich & Cook 2002, 8; Cousins et al. 2004; Khan et al. 2008, 415). Physical loss might also be related to quality loss if the reduced quality occurs in the form of faulty components and decreased yield. Example of physical loss might be for example the damage incurred to clean room facilities of Ericsson's supplier due to fire created by lightning strike (Norrman & Jansson 2004, 441). Also, the physical losses such as equipment damages should be quantifiable and quantitative in nature (see Knemeyer et al. 2009, 149). This is easy to understand as they can be based on the book or real value of the damaged assets.

Fourthly, the *social loss* seems to have been representing the loss of brand or reputation of the companies of the supply chain from the viewpoint of other parties of the chain like customer and suppliers or the general public (Jüttner et al. 2003, 203; Cousins et al. 2004; Khan et al. 2008, 415). However, the concept is here however extended to include the damage to health and safety of human resources of the supply chain and environment. These damages might include for example impact on injuries, illness, or deaths of the employees but also even disease outbreaks for the external society. (Helferich & Cook

2002, 8; Jüttner et al. 2003, 204; Knemeyer et al. 2009, 148–149; Tummala & Schoenherr 2011, 476; Leat & Revoredo-Giha 2013, 223.) The damage to human resources and the reputation seem also to be interconnected as violations of health and safety might create negative publicity for the company (see e.g. Jüttner et al. 2003, 203; Leat & Revoredo-Giha 2013, 223). Loss of human resources might create legal, regulatory, or insurance-related consequences which might be quantifiable if there is prior data available. For example, quality issues of car tire maker Firestone were reported to have led to over 200 deaths and estimated cost of over 3 billion dollars from 2000 to 2001 to Ford Motor Company (Truett 2001).

Fifthly, the *psychological loss* refers to the damage to the 'self-perception' of the organization due to risk event (Cousins et al. 2004). This can be understood in other words as loss of morale. This type of loss has not been widely discussed in the SCRM literature, but Harland et al. (2003) provide example of changed perceptions of the employees and external partners of the company due to non-compliance identified in external audit. Thus, psychological loss seems to be related to reputation impact of social loss and there might also be contradictory definitions between these two types of impact. In any case, psychological loss seems to be difficult to estimate especially in monetary terms. Hence, it is understood more as a qualitative in nature.

Sixthly, the risk event in supply chain can affect *loss of time* in supply chain operations. Forms of the time loss have been widely discussed in the literature can be in forms of delivery delays, extensions to lead time as well as extension to project schedules and time to market which might further lead to lost sales and market opportunities (Cousins et al. 2004; Norrman & Jansson 2004, Christopher & Lee 2004, 389; 454; Canbolat et al. 2008; Khan et al. 2008, 415; Blackhurst et al. 2008, 143; Tummala & Schoenherr 2011, 476). In addition, Tuncel & Alpan (2010, 254) propose that the time impact of the risk includes also the time used for solving the issue and time of for example reordering if the problem cannot be solved without running the process again. Furthermore, the time loss is related to the speed of detection of the risk proposed by Manuj and Mentzer (2008b, 196–197) if the detection and subsequent actions affect the time of impact and to the time as a risk impact driver identified by, for example, Hendricks and Singhal (2005a, 695).

Seventhly, the *quality loss* created by risk event has also been found to be part of the risk impact spectrum by for example damage to materials in transit (see e.g. Khan et al. 2008, 415; Vilko & Hallikas 2012, 590–592). Furthermore, the quality issues might have severe effect on the supply chain: for example in 2001, automotive companies specialized in high-end cars were forced to halt deliveries due to lack of leather with adequate quality (Norrman & Jansson 2004, 435). There seem to be less mentions of quality impact in the literature which might be due to the perception of quality issues as a source for e.g. physical loss, delivery delays, compensations, or lost sales rather than type of risk impact.

Eighthly, the *loss of information* has been identified by multiple authors as consequence of the risk. These losses can take forms of lack of information accessibility, efficiency, and accuracy as well as loss of data (Helferich & Cook 2002, 8; Knemeyer et al. 148–149; Hou & Zhao 2020). The inclusion of information loss to risk impact spectrum is also related to the perception of supply chains as set material, financial and information flows (see e.g. Tang & Musa 2011).

Ninthly, the impact of supply chain risk to the *natural environment* has been proposed by Cousins et al. (2004, 556). Example of such risk impact might be for example the additional emissions created by alternative logistics routes if primary routes are unavailable due to risk event. Recent example of this risk is the new routing of container ships around the Cape of Good Hope due to stuck ship blocking the Suez Canal (Ft.com 26.3.2021).

In addition to the nine classes of stressed resources or measures of supply chain, risk impact classification as per stressed party of the company and chain has been proposed by the literature. Christopher and Lee (2004, 393) propose that the impact of lack of confidence in supply chain impacts different business areas differently. For example, customer service is unable to give precise availability information, operations suffer from issues in forecasting and marketing suffers from delays in time to market and discounts given for end-of-life production. In addition, the raw material supplier needs to hold additional stock due to uncertainty of demand and long lead times are quoted to avoid broken promises. Inspired by this viewpoint, the stressed parties of the supply chain are pursued to be identified in the risk impact identification construction in addition to the risk impact based on the stressed resource or measure.

To conclude, nine types of risk impact are proposed by the literature. These forms have different properties based on their measurability: Financial loss, loss of performance, physical loss, loss of time and loss of quality are identified the most qualitative and quantifiable forms and are thus more critical for the constructions. Psychological loss and loss of information are found difficult to measure and, thus, they are in a supportive role in the constructions. Social loss and environmental loss are harder to quantify but they have certain measurable properties and, hence, they are in between the critical and supportive types of impact in the constructions. Furthermore, the identification of the parties stressed by the forms of risk impact will be included in the construction. The identified types of risk consequences are not visualized based on the literature review but the final list of risk impacts after empirical testing can be found from the Appendix 2.

3.2 Formulation of construction 1: Risk & risk impact identification tool

3.2.1 Description

The main objective of the construction 1 is to link the risk sources identified from the supply chain studied to the consequent risk impact and, thus, provide impact as the input for application of construction 2, total cost of supply chain risk tool. The sources are linked to impacts by studying the risk events which act as the intermediate trigger turning the risk sources into risk impact and the risk drivers which moderate or exaggerate the connection between sources and events or events and impact. The components of risk based on the literature review are used as a framework guiding the formulation of construction (see figure 3).

The main logic of the construction is supported especially by following viewpoints: Tummala and Schoenherr (2011) propose that risk identification phase of SCRM process should include the linking of supply chain risks and resources of the organization that are affected. As noted, Jüttner et al. (2003, 201) highlight the importance of identifying the risk sources, risk impact and risk drivers in the studied supply chain. Christopher et al. (2002, according to Norrman & Jansson 2004, 438) add that the risk should relate to the risk sources emerging from different tiers of the supply chain.

The supply chain risk and risk impact identification tool includes 3 different steps which are shortly presented below. The main data source for all the three steps of the construction are expert insight to lay basis for more quantitative calculations of construction 2. The selection of tools for the three steps is most influentially affected by the thoughts of Kwak et al. (2018, 375) who propose that systemic approach for risk identification, cause-and-effect analysis and analyzing failure modes can provide especially relevant insight for holistic approach to risk structures. However, they focus especially on risk interactions and use interpretive structural modelling (ISM) for this usage. The risk component coverages of steps of the constructions are presented in Figure 3.

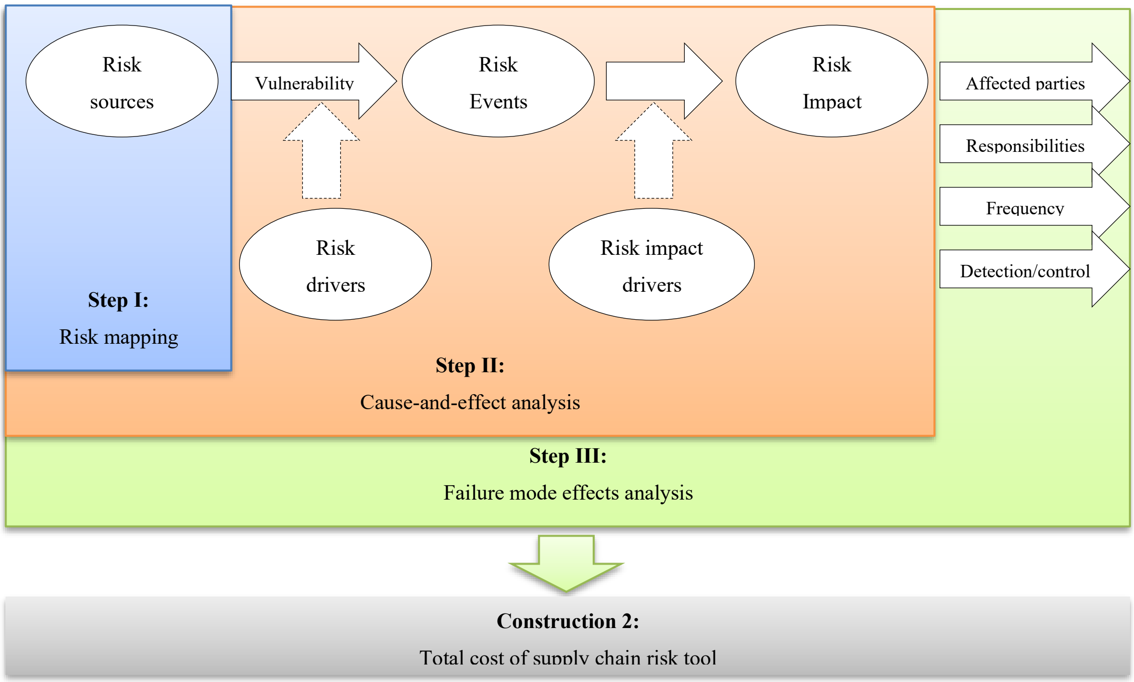

Figure 3. Steps of construction 1 & coverage of risk components.

Step I: Supply chain risk mapping. The supply chain structure, locations and flows between supply chain partners are mapped to provide visual representation of the supply chain design in hand. The risk sources emerging from the mapped supply chain partners and flows are identified based on a pre-planned taxonomy and the controllability of the identified sources by supply chain partners is identified.

Step II: Cause-and-effect analysis. The risk sources identified in step I are connected to consequent risk events and risk impact based on pre-planned taxonomy via cause-and-effect-analysis. The risk and risk impact drivers are used to provoke thoughts about the vulnerability of the chain and the dynamics of sources turning to events and further to impact. The interconnectedness of risks is distinguished by considering the risk events combined by multiple sources. The impacts in different life cycle phases of the supplied products or services are considered.

Step III: Failure mode effects analysis (FMEA). The risk source–event–impact chains are exposed to structured analysis in the framework of FMEA. The affected parties by the impact, responsibility for mitigation based on impact and source controllability, frequency, detection, and control, as well as speed of detection and business recovery time are identified and analyzed. The output of step III acts as the input for construction 2.

3.2.2 Application

The scope of one application round of the construction is limited to the supply chain in which the problem that decision-maker is facing related to for example supply chain development related to identified opportunity for cost reduction or revenue generation exists (see e.g. Manuj & Mentzer 2008b, 212; Tummala & Schoenherr 2011). However, the holistic approach related to supply chain environment and risk structures is applied in the analysis of the specific supply chain as highlighted by numerous authors (see e.g. Manuj & Mentzer 2008a, 133; Rao & Goldsby 2009, 101, 115; Vilko & Hallikas 2012, 593; Kwak et al. 2018, 375).

The time-related scope of the construction is on future risk events and impact to assist on creating proactive approach to risk management (see Norrman & Jansson 2004, 438). Thus, the construction can be identified more proactive in nature than reactive as the SCRM approaches classified by Norrman and Wieland (2020, 642, 661). The time aspect is initially considered in two other considerations of the application of the construction. Firstly, the example of Canbolat et al. (2008, 5153) of considering risk impacts related to different life cycles phases of the products or services supplied by the chain seems fruitful. Secondly, to pursue the effect of changes in risk proposed by Ghoshal (1987) and Blackhurst et al. (2008, 144) the analysis should be conducted periodically – for example, bi-yearly – and when the life cycle phase of one of the products or services changes from development to production or from production to end-of-life for the first time.

Manuj and Mentzer (2008b, 212) highlight the importance of team composition for the success of risk identification and management in general. Following the ideas of Canbolat et al. (2008, 5162), the cross-functional approach should be taken in the application of the construction by including functions such as research and development, project management, sales, and finance in addition to supply chain and sourcing. They bind the team composition to the involved functions in the decision-making and implementation of the project triggering the SCRM process. Furthermore, the inclusion of supply chain partners in the application should be considered before utilizing the construction to enable information sharing and coordination with external partners (see e.g. Kleindorfer & Saad 2005, 55, 66; Applequist et al. 2000, 2212). However, Manuj and Mentzer (2008b, 212) note that this might increase the resource need for the process significantly, and thus it should be carefully considered are the roles of the external partners closer to more distant data source or to integrated partner in application of the construction.

3.2.3 Step I: Supply chain risk mapping

The objective of the supply chain risk mapping is to provide the visualization of the supply chain structure and flows between supply chain partners and use this map to identify the risk sources emerging from the supply chain design and environment. In addition, the responsibility over sources can be assisted by the visualization as the ownership structures becomes visible (see Harland 1997, as per Harland et al. 2003). Practically, the step I includes two workflows: creation of the map and risk source identification. Thus, the two-step approach is like the one used by Harland et al. (2003, 56–59).

Creation of the supply chain map

The usage of supply chain mapping for risk identification purposes has been presented by multiple authors. Tummala and Schoenherr (2011) propose that the supply chain map should show the flows of material, information, and money between supply chain partners. Harland et al. (2003, 56–59) include the key measures of the supply chain and ownership to the mapping. In addition, they present an example of Brenchley (2000, as per Harland et al. 2003, 56–59) including the international borders in the visualization. Norrman and Jansson (2004) present a tool of Ericsson for mapping the supplier base of the product. This approach is narrower than required in the construction, but they emphasize the importance of considering availability of alternative sources in the structure which might be a relevant point for the construction as well. Rao and Goldsby (2009, 115) evaluate the risk mapping to be '*a reasonable starting point'* for risk identification.

Practically, the actual drawing of supply chain map should be conducted by a core group of experts of the supply chain design studied most probably from functions of sourcing, logistics and supply chain management. Additional functions should be invited to participate only if needed to limit the burden. As proposed by literature, the map should include the entities of the supply chain, the flows of material, information and money, the international borders as well as ownership areas of the supply chain. The key measures of the supply chain are removed from this step as they might be hard to identify early in the planning of the supply chain. The more process-oriented mapping style utilized by Norrman and Jansson (2004, 445) and Harland et al. (2003, 56–59) is preferred over geographical map to increase clarity. As proposed by Gardner and Cooper (2003, 45) the level of detail should not be too high on the map. An example of supply chain map about simple three tier supply chain is provided in Figure 4.

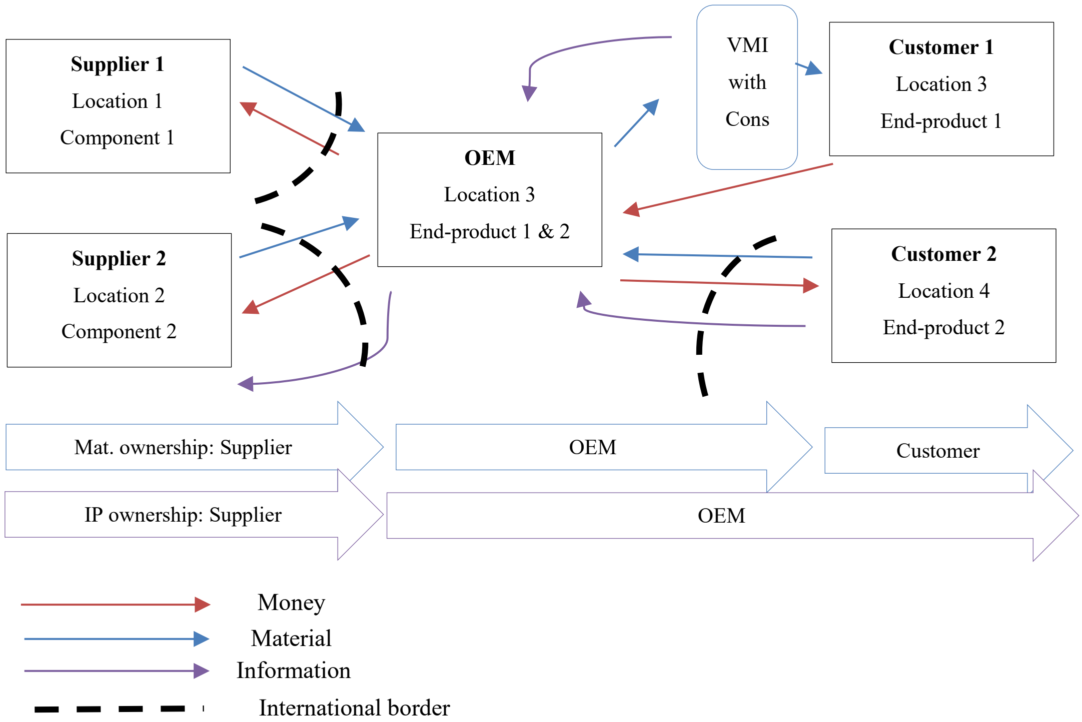

Figure 4. Simple example of a supply chain map (based on Norrman & Jansson 2004, 445; Brenchley 2000, as per Harland et al. 2003, 56–59).

Risk source identification from the supply chain map

The supply chain map creation is followed by the risk source identification. This activity is conducted by workshop of wider group including functions such as research and development, finance, and project management. Including external partners can be considered. The proposed workflow is that supply chain map discussed one entity and flow by one and risk sources are identified and classified based on pre-planned taxonomy. After entire structure have been considered, it is checked whether there is location or flow independent risks emerging as well. The controllability of the risk source by the supply chain partners is assessed as well based on which party can control the source or whether any party can. Similar kind of controllability evaluation of risk has been proposed by Wu et al. (2006, 351). For example, the certain natural accidents are uncontrollable by any party of the supply chain but financial troubles of one supplier can sometimes be controlled by itself or influenced by other parties of the chain. Special attention is given to availability of alternative sources as proposed by Norrman and Jansson (2004, 445). The risk taxonomy based on operational, low magnitude but high frequency, or disruption risk is not used yet in this step, as the evaluation of impact in later steps seem to be beneficial.

Table 4. Risk source identification table (based on Wu et al. 2006; Blackhurst et al. 2008; Tang & Musa 2011; Hou & Zhao 2020).

Flow	Type	Risk source	Location in SC map	Controllable by...
Material	Capacity	*Machine unreliability*	*Supplier 1*	*Supplier 1*
	Quality			
	Inventory			
	Logistics			
	Security			
Information	Information systems			
	Forecast			
	Intellectual property			
	Security			
	Management /relationship			
Finance	Supplier commercial			
	Customer commercial			
Other/ multiple flows	Legal			
	Dependence			
	Disruptions/disasters (incl. environment, politics etc.)	*Economic instability* *Labor strikes*	*Location 3* *OEM -> Customer 1*	-

The working table for the activity based on the risk source taxonomy of Blackhurst et al. (2008) can be found from Table 4. As proposed by Blackhurst et al. (2008, 148–149), the risk taxonomy should be tailored for the specific industrial and supply chain context. Due to the industrial context of the Client company of this thesis, the automotive-based risk taxonomy utilized by Blackhurst et al. (2008) will be used as starting point in the construction, but some of the risk source classes are modified for interpretability and the dimension of internal or external risk is replaced with controllability. The risk source types based on the taxonomy of Blackhurst et al. are further divided into material, financial and information related sources to assist the linkage to flows of the map and different types of risk impact (see e.g. Tang & Musa 2011; Hou & Zhao 2020). This taxonomy might not be applicable to other contexts and if the applying entity has an existing and well-tailored taxonomy in place that can be used as well.

3.2.4 Step II: Cause-and-effect analysis

The outcome of step I, identified risk sources, is further analyzed in cause-and-effect analysis to link the sources with consequent risk events and risk impact. The interconnection of different risk sources and effect of risk drivers are also addressed to support the holistic approach to risk structures.

The utilization of cause-and-effect has been discovered by multiple authors: Sanchez-Rodrigues (2010) performed analysis in the context of logistics uncertainties and Kwak et al. (2018) combined the method with evaluations of interpretative structural modelling. However, the cause-and-effect analysis approach taken here can be found simpler in nature than theirs due to efforts to avoid the complexity of the entire construction. In addition, Gaudenzi and Borghesi (2006, 118) propose usage of scenario planning with brainstorming to support risk evaluation. Cause-and-effect analysis can be understood to consist of scenarios as well. Furthermore, the similar kind of methodology of event tree analysis (ETA) which focuses on analyzing the logical path from root cause to consequences has been discussed by multiple authors in SCRM context (see e.g. Norrman & Jansson 2004; Tummala & Schoenherr 2011). As can be identified from the work of e.g. Cigolini and Rossi (2010, 455) the probabilities of logical connections are usually addressed in ETA. However, this approach is not taken in this construction to simplify the analysis and avoid the noted issues with risk probabilities. Thus, the step is called in construction a cause-and-effect analysis.

The cause-and-effect analysis is conducted by addressing the following 5 themes related to identified risk sources to formulate the pathway to risk event and risk impact. The themes can be addressed, for example, in another workshop session in the same team used in step II. Such usage of knowledge of managers for identifying the risk impact of risk sources has been supported by Gaudenzi and Borghesi (2006).

1) *What adverse risk events the identified sources cause?*

   The idea of the theme is to form the connection between identified risk sources and risk event as the by-product of the source. The importance of separating the risk events from sources is emphasized by, for example, Bandaly et al. (2012, 261–263) due to different risk management methods of different relationships.

2) *Does any other risk source contribute to source-event relationship or trigger an occurrence of other risk source?*

   The idea here is to support the holistic approach to risk analysis by finding the interconnections between risk sources. The interconnections of risk sources in risk analysis have been emphasized by, for example, Hou and Zhao (2020).

3) *Do any risk drivers affect identified relationships?*

   The risk drivers identified; complexity, integration, lack of confidence, visibility, control, and slack as well as perception of risk; are used to awake thoughts about the identified relationships between risk sources and events. By considering the risk drivers, new risk sources, events and relationships might occur as well. Especially, the example of Jüttner et al. (2003) is followed in considering the drivers.

4) *What risk impact the identified risk event causes?*

   With this theme, the relationships between identified risk events and the taxonomy of 9 types of risk impact; financial loss, loss of performance, time, quality, physical, social, psychological, information and environment; is established. Naturally, various risk events might lead to one type of impact and one risk event might lead to various types of impact. However, it is important for the total cost of risk assessment in construction 2, that all the identified risk impact are fit inside one of these 9 classes of risk impact. The classification of risk source taxonomy based on flows might help this activity.

5) *Do any risk impact drivers affect identified relationships?*

   The risk drivers identified; influence, size of the SC partners, environmental context and life cycle of the products supplied by chain; are used to awake thoughts about the identified relationships between events and impact. Special emphasis is given on the effect of life cycle of the products supplied by the chain (development, production, end-of-life) as has been proposed by Canbolat et al. (2008, 5153). By considering the risk impact drivers, new events, impacts and relationships might occur as well.

The outcome of the step II should be a holistic risk structure of the supply chain studied including the components of risk sources, risk events, risk impact, risk drivers as well as their interconnections. This risk structure is used as an input for step III, but it can also contribute significantly on finding the sources and drivers which can be influenced to mitigate the risks in means outside of the scope of the constructions of the thesis.

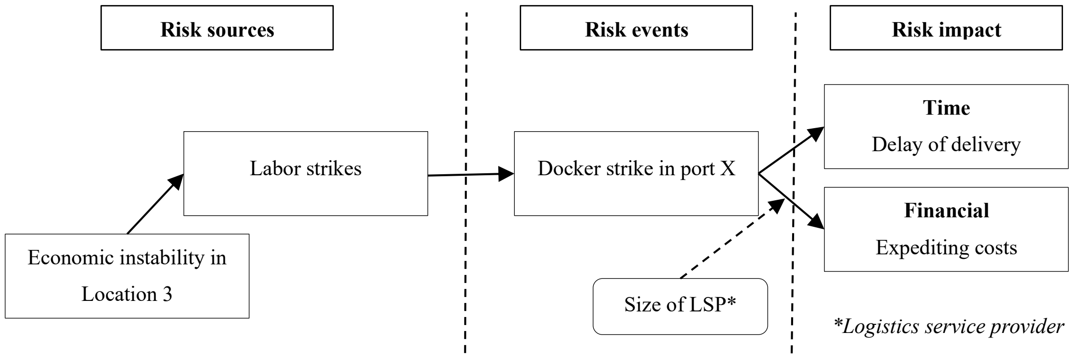

Figure 5. Graph example of cause-and-effect analysis visualization (inspired by Kwak et al. 2018).

The results of the cause-and-effect analysis can be visualized in graphs similarly as have been done by Kwak et al. (2018) and proposed by Gaudenzi and Borghesi (2006). The simple example of this approach is taken in figure 5. Other option is to form the similar information in table structure in MS Excel environment. This approach is visualized in table 5. The former might be more illustrative while latter might be more effortless.

Table 5. Table example of cause-and-effect analysis visualization.

Risk sources	Risk drivers	Risk events	Risk imp. drivers	Risk impact
Economic instability in Location 3 -> Labor strikes	-	Docker strike in port X	Size of LSP	Delay of delivery (Time) Expediting costs (Financial)

3.2.5 Step III: Failure mode effects analysis

The identified source-event-impact chains in cause-and-effect analysis are exposed to systematic analysis in step III by using approach based on the framework of failure mode effects analysis (FMEA). The objective of this activity is to provide a more in-depth analysis of the risk structures as well as provide the starting point via especially time-related evaluations of risk for the total cost of risk assessment in application of construction 2 which will be utilizing the FMEA framework as well. This objective requires already some assessment of risk and, thus, the step III can be located somewhere between risk identification and risk assessment phases of generic SCRM process.

FMEA or process FMEA (PFMEA) as it is usually known in managerial context is familiar tool for automotive and some other technologically mature industries. FMEA can be used for evaluating the risk events, sources, and impact, specify mitigation actions and tracking of changes. In addition, the framework assists on documenting the SCRM process. (Canbolat et al. 2008, 5152, 5156.) According to Tummala and Schoenherr (2011) FMEA is a suitable tool for proactive risk evaluation of risk events and impact before deciding on the commitment to specific supply chain. In addition, Kwak et al. (2018, 375) highlight the analysis of failure modes to address and understand holistic risk structures. Furthermore, in idea level, the FMEA can be seen to be related to risk profile thinking proposed by Manuj and Mentzer (2008a) where different risks are analyzed in different measures, for example, in terms of quantitative versus qualitative and domestic versus global, in table tool.

Due to its managerial familiarity in the automotive context and suitability for creating the bridge to risk evaluation in addition to identification, the FMEA framework is proposed to be utilized in this step. The example of Canbolat et al. (2008) about application of FMEA in empirical setting in automotive industry is considered especially prominent in here. In addition, the utilization by Tuncel and Alpan (2010) of FMEA related tool of failure mode, effects and critically analysis (FMECA) based on military standards will provide another basis for the construction.

The measures which the identified risks will be analyzed in on step III will be presented next (see also Table 6). It is proposed that the analysis should be conducted with similar workshop group which was involved in the cause-and-effect analysis of step II to secure continuity. Due to the preceding steps of risk mapping and cause-and-effect analysis and the risk concept framework behind the construction (see figure 3), there will be slight differences to approaches of Canbolat et al. (2008) and Tuncel and Alpan (2010) in terms of the analyzed items. Related factors of these models are listed in table 6. It is worth noting, that due to the familiarity of the Client company to the FMEA framework, the proposed construction will see significant development on the empirical study, and, for example, the actual way of measuring will be determined, or certain measures can be found irrelevant for analysis and be removed from the final construction.

Table 6. Factors of FMEA model of construction 1.

Factors in FMEA of step III	**Source step of construction 1**	**Measure**	***Related factors in other FMEA/FMECA models***	
Risk source	I		*Cause of failure*	*Canbolat et al. 2008* *Tuncel & Alpan 2010*
Source location	I		*Entity/process step*	*Tuncel & Alpan 2010*
Source controllable by...	I		-	-
Risk drivers	II		-	-
Risk event	II		*Failure mode*	*Canbolat et al. 2008* *Tuncel & Alpan 2010*
Risk impact driver	II		-	-
Risk impact (failure effect)	II		*Effects of failure*	*Canbolat et al. 2008* *Tuncel & Alpan 2010*
Affected party by impact	III		-	-
Responsible of managing	III		*Responsible organization*	*Canbolat et al. 2008*
Frequency	III	Per time span (e.g. times/year)	*Probability (0–1)* *Occurrence (1–10)*	*Canbolat et al. 2008* *Tuncel & Alpan 2010*
Detection / current controls	III		*Detection / current controls*	*Tuncel & Alpan 2010*
Speed of detection Business recovery time	III	Time (e.g. days)	*Detection score (1–10)*	*Tuncel & Alpan 2010*
Severity	Construction 2	Total cost (€)	*Monetary Impact (USD)* *Severity (1–5) / Risk priority number (1–1000)*	*Canbolat et al. 2008* *Tuncel & Alpan 2010*

The risk events, risk sources and risk impact from steps I and II will be included the FMEA table. In addition, the factors of source locations and controllability (from step I) as well as risk drivers and risk impact drivers (step II) will be included in the table to assist on evaluations and for documentation purposes. The terms used in FMEA model provide a clear bridge to SCRM concepts which promote the usage of FMEA to SCRM. According to Canbolat et al. (2008, 5152), 'failure mode' is used to represent the manner of failure in system. The approach of Tuncel and Alpan (2010, 254) is followed, and failure modes and supply chain risk events are used interchangeable. Furthermore, the 'failure cause' will be used interchangeably with risk source and 'failure effect' with risk impact. This seem to be close to the approach used by Canbolat et al. (2008, 5158) in their

FMEA table as well. It also worth noting, that Canbolat et al. (2008, 5151–5152) use '6M' model, including sources related to machine, manpower, mother nature, method, material, measurement systems, as a basis for risk source identification. The other risk source taxonomy has already been used in step I so the 6M will not be used.

The first evaluation of the FMEA will be done related to affected party by the risk impact and responsible party of managing the risk. The need for identifying the affected parties by the risk impact is supported by the idea of Christopher and Lee (2004, 393) that impact can be different for different business areas. Thus, the affected parties of the focal company, companies in the supply chain and external parties will be identified. This identification together with the source location information and controllability information from risk mapping of step I will be used the identify the stakeholders inside the company that should be responsible of management of the risk. The benefit of activity is to assign responsibility for mitigation work which is, however, outside of the scope of the constructions. This is close to the approach of Canbolat et al. (2008, 5151–5152, 5158) who assigned the responsibilities of risk mitigation to organizations involved in supply chain project triggering the SCRM process. Similarly, the organizations included in SCRM workshops in which the steps I to III are conducted can be used. The approach of Canbolat et al. can be extended to include other parties of the supply chain as well especially if they are involved in the SCRM workshops.

Secondly, the probability or occurrence evaluation of the risk impact used in the FMEA models by Canbolat et al. (2008, 5157) and Tuncel and Alpan (2010, 253) will be replaced with component of risk frequency proposed by Manuj and Mentzer (2008b, 196–197). This is done due to the problems related to the risk probability evaluations proposed by, for example, Manuj and Mentzer (2008a, 140), March and Shapira (1987, 1407–1408) and Norrman and Jansson (2004, 446). Furthermore, Manuj and Mentzer (2008b, 197) propose that frequency together with components of speed can be used to determine the losses per time. In the construction, the subjective and rough evaluation based on managerial experience is preferred to be used to limit the burden of the FMEA. Risk frequency should be evaluated with understandable measure like times per year which is harder to conduct with risk probability as noted by Norrman and Jansson (2004, 446).

Thirdly, the detection method and current controls of risk event is identified and set of time related rough evaluations are performed based on subjective managerial experience. The detection method and current controls of risk event used by Tuncel and Alpan (2010, 253) in the FMECA table is related to different methods of identifying happened risk event like statistical process control and information sharing and, as well, stating how the risk is currently controlled. However, the risk detection scale of 1 to 5 or 1 to 10 used by them to indicate the difficulty of risk detection and control will be replaced, firstly, with time related measure of speed of detection proposed by Manuj and Mentzer (2008b, 196–197) and, secondly, the time the risk is having an impact for the supply chain called 'business recovery time' (BRT) as proposed by Norrman and Jansson (2004). This approach is again aligned with the usage of understandable measures highlighted by Norrman and Jansson (2004, 446).

Finally, as done by Canbolat et al. (2008, 5154–5155), the risk severity score of 1 to 10 will be replaced with monetary evaluation. This will be conducted by total cost of risk assessment of construction 2. Thus, the score, and the subsequent risk priority number (RPN) utilized by Tuncel and Alpan (2010) will not be provided but the prioritization of the risk will be based on the monetary value. This again, is aligned with the view of Norrman and Jansson (2004) about the understandability of the measures by managers.

3.2.6 Theoretical evaluation of construction 1

In this chapter, the supply chain risk and risk impact identification tool of construction 1 will be theoretically briefly evaluated against the identified design principles for SCRM constructions. The coverage of different design principles is summarized in table 7. In addition, alternative methods of risk identification not included in construction are reviewed to further justify the made design decisions. This activity is conducted to anticipate the usability of the construction based on the theoretical basis before the actual implementation in the empirical setting.

Table 7. SCRM construction design principle coverage of construction 1.

#	Design principle	Coverage in construction 1
1	*Holistic approach*	Supply chain parties and risk structures Interconnectedness
2	*Business-oriented quantification*	Measures used (frequency, time)
3	*Proactive approach & lessons learned*	Orientation on potential future risks Experience of participants
4	*Cross-organizational approach*	Cross-functional activity Considering level of involvement of other SC parties Responsibilities determined
5	*Industrial context*	Taxonomies Risk drivers

Design principle 1, the holistic approach to risk, is applied by pursuing to consider the wide set of supply chain parties in addition to the focal company and direct customers and suppliers. In addition, the risk structure in including the wide set of supply chain risk components and the interconnection of risks is considered.

Design principle 2, quantification, and measurement with business-oriented manner, is supported by using the more understandable measures of frequency and time instead of scales used by some authors to evaluate occurrence or detection (see e.g. Norrman and Jansson 2004, 446; Manuj & Mentzer 2008b, 196–197; Vanany et al. 2009, 25–26).

Design principle 3, proactive approach supported by lessons learned of the past, exists in the construction via the usage of tools to assess potential risks in the future. In addition, the evaluations of experts involved in the application of tools might be guided by their past experiences and lessons learned from there.

Design principle 4, using cross-organizational and cross-functional approach without forgetting one's own responsibility of common targets, is covered by conducting the application of tools by cross-functional activity and considering the level of involvement of other SC parties in the process. In addition, the responsibilities of managing risks are determined among the participants which helped to establish sense of responsibility.

Finally, design principle 5, industrial context utilization without binding applicability to it, is supported by applying the industry-specific risk source taxonomy and reserving flexibility on applying the preferred risk classifications of the users. In addition, the industrial context is addressed as a risk impact driver.

In addition to risk mapping, cause-and-effect analysis, and FMEA, literature proposes a wide set of other tools related to risk identification and analysis – for example, HAZard and Operability (*HAZOP*) analysis by Adhitya et al. (2009), analytic hierarchy process (*AHP*) by, for example, Gaudenzi and Borghesi (2006) and interpretative structural modelling (*ISM*) by Kwak et al. (2018). However, the risk mapping, types of cause-and-effect analysis including fault or event tree analysis as well as iterations of FMEA model are all widely proposed as suitable methods for risk identification and analysis (see e.g. Norrman & Jansson 2004, 438; Gaudenzi & Borghesi 2006; Tummala & Schoenherr 2011, 476). These three steps were selected over the others due to the excellent match of FMEA to automotive environment as well as due to aspiration to limit the amount of labor created by risk identification which could possibly have been difficult with the diligent application of the detailed SC parameter manipulations of HAZOP or multi-round formulation of risk interconnections in ISM. In addition, logic of AHP method starts from the

SC objective structures and priorities, and, thus, the application of tools starting the analysis from risk sources of the SC structure were considered more suitable for the logic of risk structure framework of the construction.

As a conclusion, the construction formulated based on literature insight is found to be supporting the practical motivation and research gaps of the thesis as well as identified SCRM design principles with few deviations. Thus, the usability of the construction 1 as a basis for construction 2 and as an object of testing and development in empirical setting is anticipated to be satisfactory. However, especially due to the risk component structure framework used as a background for the construction (see Figure 3), none of the steps used in a construction are one-to-one replications of a proposed SCRM tools and, thus, the validation is appointed to general idea of tools rather than internal logic of specific tools proposed by the literature.

4 TOTAL COST OF SUPPLY CHAIN RISK

In this chapter, the construction 2 – tool for estimating the total cost of supply chain risk – is developed for manager and team responsible for risk management of a certain supply chain to assess the monetary impact of risks identified in the steps of construction 1. Furthermore, the construction 2 supports the creation of cross-functional understanding of supply chain risk in organization and prioritization of risks as well as establishing justification for SCRM strategies by supporting the cost-benefit analysis of SCRM with cost information about impact of the risks in the supply chain. Foundation of the tool emerges from the literature of total cost of ownership (TCO) – one of the influential supply chain management frameworks of 1990s and 2000s. The greatest contribution of the chapter is related to the research question 2 by presenting a way of working for assessing the total cost of supply chain risk. In addition, research gaps of 1, 2 and 3 are contributed on the chapter. Furthermore, the theoretically based tool formulated in this chapter will be tested and further developed in the empirical study in the supply chains of the Client company, and thus the contribution for research gap 4 is supported.

The chapter is organized as follows: Firstly, on chapter 4.1, the main principles, benefits, boundaries, and connection to risk management of total cost of ownership are presented to lay the theoretical foundation from TCO literature to support the creation of construction 2. Especially, the focus is given to the TCO-related work of Lisa Ellram throughout the 1990s and early 2000s. Secondly, on chapter 4.2, the cost components of risk impact are presented from the literature of SCRM to create the objects for cost assessment in the construction 2. The components are tied to the classification of 9 types of risk impact, to form a solid bridge to the impact of risk identified and organized with cost-and-effect analysis and FMEA work of construction 1. Finally, in chapter 4.3, the construction 2 is formulated based on the principles of TCO literature and cost components of SCRM literature. Further support is provided from risk assessment frameworks of SCRM literature. The construction 2 is then theoretically evaluated against the identified design principles to anticipate the usability of the construction in empirical setting.

4.1 Concept of total cost of ownership (TCO)

4.1.1 Definition

According to Ellram and Siferd (1998, 56), total cost of ownership (TCO) approach is focusing on determining the most significant costs of purchasing a product or service from a supplier. In TCO approach, these costs are not limited to the purchase price but include wide set of different cost components including validation of suppliers, order placement, logistics, receiving, warehouse operations and possible disposal. They also highlight that TCO is not just a tool but also a philosophy towards cost of purchased items. Ellram (1995, 6) note that TCO has its roots on transaction costs analysis which also emphasizes the importance of extending the scope of costs out of the price alone.

The TCO has been primarily a procurement-related approach. Ellram and Siferd (1998, 55) propose that procurement functions have the main responsibility of the largest share of the costs of the organization through the cost of purchased products and services. This cost in many cases exceeds the internal manufacturing costs. Thus, it is natural, that TCO has seen usage especially on supplier selection activities by supporting on selection of the supplier with the lowest total life cycle costs including all costs viable for quantification as has been suggested by Tang (2006, 456). The examples of TCO usage can also be found from wide set of different industry contexts (Hasan et al. 2020, 26).

4.1.2 TCO connection to SCM and risk

In addition to the procurement, the TCO has been linked to the wider concept of supply chain management. Already in early 1990s, Ellram (1993a, 59) proposed applying the TCO approach to entire supply chain costs as an idea for future research. The need for similar supply chain focused TCO model was highlighted by Ferrin and Plank (2002, 18) as well. This is logical when compared with the thinking of Franca et al. (2010, 293). They propose that supply chain management is responsible of the optimization of the total cost of supply chain operations in the levels of supply chain. This responsibility is similar to the one of procurement highlighted by Ellram and Siferd (1998, 55).

Furthermore, the concepts of TCO and risk has been connected in the literature by various authors. Kumar et al. (2010, 3717–3719) suggest that the risk factors of the supply chain are always related to the cost, and they influence the efficiency of the supply chain by impacting the procurement cost as well as time. This impact leads to decrease of profits and optimal strategy minimizing both risks and costs should be pursued. Zsidisin et al. (2000, 196) propose that the assessment of total costs of risk event is an important activity for balancing the risk and risk mitigation strategies. Furthermore, Rao and Goldsby (2009, 115–116) argue that risk from suppliers can be included in a set of different supplier selection models, including total cost of ownership.

In addition, van Hoek (2020b) proposes that the more uncertain and riskier environment due to Covid-19 pandemic seem to also increase the relevance of TCO concept. According to them, the logic behind is that the availability issues and logistics cost increases has been eroding the benefits of low purchase price by sourcing from for example China. Thus, the dynamics of comparison of the total cost of sourcing from nearer locations with improved availability and lower logistics cost with sourcing from lower purchase price locations are changed. However, they also point out that the importance of revenue and customer satisfaction considerations together with the TCO as customers may be willing to compensate the improved availability. Hence, due to the Covid-19 they highlight the importance of adjusting the TCO concept to dynamic environment and balance with non-cost factors (see also Hoek 2020a, 341, 351).

Regardless of these connections between concepts of TCO and risk, the set of applications combining these concepts is existing but narrow. Prabhakar and Sandborn (2012) evaluate the effect of long-term supply chain disruptions to usage of same components in multiple products, or 'design reuse', using TCO-based model in electronics industry. Micheli et al. (2009, 166) combine the supply chain risk impact costs and costs of managing risk in risk-efficiency-based supplier selection (REBaSS) framework using TCO approach as basis in engineering, procurement, and construction industry. In addition, Hasan et al. (2020) present the usage of TCO model in formulation of public policy in high-risk supply chains. However, in this case, the risk seems to be considered more as a context factor than component of the TCO assessment.

As can be seen, the interest in combining the concepts of supply chain, risk and TCO has been presented by multiple influential authors in the past. However, the research of tools and other applications combining these concepts seem not to have reached maturity. In addition, the concept of risk has been utilized more in the literature of TCO supplier selection models than the TCO has been utilized in SCRM literature. Motivated by these findings, principles, benefits, and challenges of TCO from the literature are connected with the principles and other components of SCRM to support the formulation of construction 2 and the contribution to research gap 3, connection of SCRM and TCO.

4.1.3 Principles of TCO

Literature of TCO presents multiple principles of total cost of ownership approach. In this chapter, these principles are compared to the SCRM design principles and factors of supply chain risk to strengthen the connection between the concepts of TCO and SCRM and to evaluate the usability of TCO for SCRM applications.

Firstly, the TCO approach is based on comprehensive view of the costs created by purchase or supply chain (Hasan et al. 2020, 26). In addition to the purchase price, costs related to sourcing, receiving and usage of material including the possible impact of defects (Ellram 1994, 171). In other words, the life cycle costs are included in the assessment (Ellram 1993b, 4). As has been proposed by Ferrin and Plank (2002, 29) the focus on TCO approach is on reducing and managing the indirect cost. This comprehensive principle of TCO seem to be supporting well the first design principle for SCRM constructions: the holistic approach to risk and supply chain.

Secondly, as can be derived from the name of concept, the TCO is driven by monetary approach. Ellram and Siferd (1998, 57) justify this focus on dollar values on the tendency of scale-based qualitative assessments to deprioritize the indirect cost and cost for performance of supplier. However, Ellram (1995, 12–14) propose that value-based TCO approach with weightings can be used to evaluate the areas difficult to evaluate with monetary values. The monetary evaluation is well aligned with the second design principle of business-oriented measurement. Furthermore, the focus on evaluation of risk impact rather than probability due to understandability for business decision-makers noted by Norrman and Jansson (2004, 446) is supporting this alignment.

Thirdly, according to the Ellram (1994, 171) the TCO is proactive philosophy in nature. The rationale behind this is that the extensive data collection for TCO activities must lead to usage of analysis for decision-making. Thus, the TCO is applied as a proactive tool supporting the decision-making a priori. The support for design principle 3, proactive approach for SCRM, seem to be established.

Fourthly, the TCO is by nature a philosophy promoting cross-functionality and interorganizational view. Zsidisin and Ellram (2001, 632–633) promote the cost information sharing in supplier-customer relationship when applying TCO. Ellram and Siferd (1998, 58–59) support this viewpoint. In addition, they highlight that the TCO approach address this connection by evaluating the supplier performance impact for total cost. Furthermore, they promote the consideration of whole value or supply chain cost impact in TCO analysis. Internally, the TCO approach is proposed to be applied by involving other functions than purchasing on data collection of TCO as all the cost data and knowledge cannot be found from one single function and other functions might be affected by the decision-making situation (Ellram 1993b; Ellram 1993a, 52–53; Ellram 1994, 188). Mentioned functions to involve, for example, finance, engineering, quality, logistics and IT (Ellram 1993b; Ferrin & Plank 2002, 27). The design principle 4, cross-organizational and cross-functional approach, seem to be closely related to the TCO literature. Furthermore, the supply chain approach of TCO provides further support for holistic approach of SCRM.

There seem to exist academic discussion about the context-specificity of the TCO models. To limit the burden of TCO formulation, the standard models, used for all kinds of purchase situations, are proposed to be utilized whenever possible by Ellram (1995, 20). However, they suggest that when this is not possible, the fitting cost elements should be selected from pre-prepared listing for the specific situation. Similar kind of approach is advanced by Ferrin and Plank (2002, 18, 26–27). They propose that set of 'core cost drivers' would be used in all of the applications of TCO. In addition, set of 'specific cost drivers' would be selected to support the context of specific application of TCO model. These considerations of context seem to provide support for including the industrial context to SCRM but securing generalization of the constructions which is the core message of design principle 5. Furthermore, the usage of standard list of cost components might become useful in assessing the cost of risk impact types in construction 2.

Finally, in addition to the design principles, the TCO concept seem to include similar consideration of time and change than concept of SCRM: Ellram (1993b, 4) stress the importance of evaluating the entire life cycle costs of decision-making object like item ordered from certain supplier. This is understood as creating a long-term orientation for purchasing and cost evaluation by various studies (Ellram 1993a, 51; Ellram 1995, 7–8; Ferrin & Plank 2002, 18). Furthermore, Ellram (1994, 189) highlight the change-orientation in implementing TCO as the environment and focus of the organization using TCO is in constant change. Time is in the center of SCRM concepts by, for example, components of speed and frequency of risk as well as recovery time which are included already in the FMEA tool of construction 1. Furthermore, the time has been identified as one of the drivers of risk via the duration of risk impact and the effect of life cycle phase of products supplied by supply chain. In addition, the change has been identified as a core characteristic of supply chain risk as well (see e.g. Ghoshal 1987; Canbolat et al. 2008, 5153; Blackhurst et al. 2008, 144).

4.1.4 Benefits and challenges of TCO

In this chapter, the selected benefits of TCO approach are linked to SCRM activities to further strengthen the justification of TCO utilization in the construction 2. In addition, the barriers, and challenges for TCO implementation are reviewed to set preconditions and tackle possible issues with the TCO approach application.

Firstly, the TCO approach enables the performance measurement, determination of performance expectations and especially in the context of supplier base to drive the continuous improvements (Ellram 1995, 7–8; Micheli et al. 2009; Zachariassen & Arlbjørn 2011, 450). This seem to be very suitable basis for SCRM implementation as the performance related to risk and improvements to the current situation by risk management strategies is in the very core of the SCRM approaches. This driving force for improvements is further supported by the ability of TCO to prioritize the components of total cost to identify the most important areas of improvement (Ellram 1993a, 51; Ellram 1994, 172). Ellram (1994, 171) propose that the priorities respect the idea of Pareto's Law: the aim is to identify the 20 % of cases that are responsible of 80 % of cost. Furthermore, TCO provides basis for justifying the increased purchase price with improved total cost or level of quality and determine the level of sustainable cost for improved performance in supply chain (Ellram 1993a, 51; Ellram 1995, 7–8). In addition, the TCO provides exceptional data and means of communicating the cost insight for decision-making and negotiations. This is supported by the practicality of working with a single monetary value as an outcome of TCO. (Ellram 1993a, 51; Ellram 1995, 7–8; Micheli et al. 2009.)

The value of these benefits of TCO to SRCM work become visible when they are compared with the main needs to measure the risk impact which is the aim of the construction 2: The need for prioritization of SCRM work in the environment of scarce resources seem to match well with the priority-focus of TCO (see Tuncel & Alpan 2010; 257; Kwak et al. 2018, 383). The justification for right level of SCRM capabilities with business case including monetary evaluation of risk impact is very consistent with the idea of cost-benefit analysis of price, total cost, and performance in TCO framework (see Rice & Caniato 2003; Chopra & Sodhi 2004, 56; Hendricks & Singhal 2005b, 36; Pettit et al. 2010; 2013). Finally, the practical way of communication with monetary values for decision-making might provide outstanding support for the main purpose of risk impact assessment proposed by Knemeyer et al. (2009, 148–149): establishing cross-functional understanding about risk consequences and environment.

Despite the benefits of the TCO approach, the number of challenges exist when the approach is utilized: First and foremost, the complexity level of TCO approach is high due to difficulty of obtaining the necessary data. The information systems to support the implementation are not often in place and, thus, the data collection must be focused outside the normal systems of the organization which is usually a resource intensive practice. (Ellram 1994, 175–176; Ellram & Siferd 1998.) Thus, as studied by Ferrin and Plank (2002) due to the complexity and challenging nature of TCO and cost drivers it is not a surprise that many companies self-assess not to show excellent performance on TCO implementation and identification of relevant drivers of cost. However, this problem of complexity and resource allocation can be fought with, for example, implementing automated systems for data collection (Ellram & Siferd 1998, 68–71). Furthermore, the TCO is usually firstly focused on non-repetitive purchases with high importance from, for example, monetary and management point of view. This is also related to the issue that cost of TCO implementation should not exceed the benefits which makes the TCO non-suitable for cases with large enough benefits are not acquirable. (Ellram 1994, 187–188; Ellram & Siferd 1998, 63, 68–71; Ferrin & Plank 2002, 23.) Thus, the challenges of data collection and suitability for decision-making circumstances with limited benefits of analysis are very relevant.

Secondly, the more qualitative cost drivers like trust, support and capabilities create a challenge for TCO implementation as they are considered difficult to quantify (Ferrin & Plank 2002, 26). As has been noted by van Hoek (2020a, 2020b) the importance of qualitative factors like customer satisfaction and flexibility are gaining more importance due to Covid-19 effects on supply chains. The challenge for the construction 2 as well, is whether to include qualitative factors and how to quantify them.

Other challenges linked to TCO implementation are related to resource-intensive sharing of data and communication openness in the supply chain (Hasan et al. 2020, 26). Furthermore, the unavailability of data from, for example, supplier with no current business relationship might create challenges for usage of TCO (Ellram 1995, 21). In addition, the cultural challenges might create resistance amongst the users and need for sales skills for the implementing party (Ellram 1994, 175–176; Ellram & Siferd 1998, 68–71).

Regardless of the issues of TCO approach, Ellram (1994, 173) propose that based on the feedback of practitioners the benefits of TCO exceed the cost and challenges of implementation. Furthermore, to tackle the issues of TCO, Ellram (1994, 188) propose sensitiveness to issues, cross-functional co-operation, and top management support to ensure needed resources as well as training both internally and externally. In addition to these, Ellram and Siferd (1998, 72) suggest development of suitable approach in narrower setting before wider implementation to organization. Furthermore, the user-friendliness and flexibility of TCO model is promoted by them. To tackle the issue with lack of data, Ellram (1995, 21) advance the idea of 'conservative convention'. In other words, the unknown entity like new supplier is evaluated based on the worst-performing known entity like current supplier. This approach usually allows better performance than expected in addition to reserving buffer in estimates for unexpected issues with new partners.

Based on the review of current connection of TCO and risk, connection of TCO principles and benefits with SCRM design principles, and challenges of TCO approach, the total cost of ownership will be implemented into the construction 2 by taking a total cost approach to supply chain risk. This will be done by considering the comprehensive or 'total' set of cost components including indirect cost as well as considering the dimension of time related to cost. Furthermore, cross-functional, proactive, and business-oriented approach taking into account the cost components for different contexts of application will be utilized as per the already established design principles. In addition, the ability to support the prioritization of risks, justification for right level of SCRM activities as well as communication in monetary terms will be supported by the construction. Finally, the realization of challenges of TCO including complexity, data availability and evaluation of qualitative factors will be followed up in the empirical study.

4.2 Cost components of risk impact

In this chapter, the cost components driving the increase of revenue effect of risk impact are reviewed based on the literature of SCRM. This activity is conducted to establish the cost evaluation objects for total cost of risk impact assessment in construction 2. To ensure smooth connection to construction 1, the cost components are classified based on 9 types of risk impact: financial, performance, physical, social, psychological, time, quality, information, and environment. The wide set of cost components is utilized to support establishing the comprehensive approach of TCO for the construction 2. However, the SCRM literature is not excessive on providing cost components to cover every aspect of risk impact and the level of depth varies. Thus, these gaps in SCRM literature will be addressed in the empirical study in the supply chains of the Client company.

4.2.1 Cost of financial loss

The financial loss of risk impact can be further classified into impact on sales and impact on cost as was proposed by Hendricks and Singhal (2005a, 696). Furthermore, the shareholder value might create cost impact via changes in shareholder value (Hendricks & Singhal 2003). In the context of the holistic approach of this study, the revenue impact via sales is considered as a part of 'total cost' as a negative financial and measurable impact of risk. In addition, some specific cost components like penalty costs related to lost sales will be classified under sales impact due to connection to lost sales even though they might be classified under cost impact by other studies (see e.g. Hendricks and Singhal 2005a).

According to Hendricks and Singhal (2003, 503–504; 2005a, 696) the *financial impact on revenue* is generated from the components of lost sales and market share, decreased sales price, and lost opportunities of high market demand if products are not available. Canbolat et al. (2008, 5154–5155) propose quantifying the financial impact on revenue if customer delays happen via opportunity cost: sales margin of the product is multiplied by rate of daily sales and the duration of delay. They also note that carried inventory has effect on the calculation as the inventory can be used to satisfy demand during delay. Duration of delay seems to be close to the concept of business recovery time proposed by Norrman and Jansson (2004). Additional cost component proposed by literature are cost of backlogging referring to increased cost of delivering delayed order (Tuncel & Alpan 2010, 256). Similarly, Silbermayr and Minner (2016, 234) propose penalty cost of unsatisfied demand and Sawik (2015, 60) connect this penalty cost to delayed deliveries as well. In addition, Silbermayr and Minner (2016, 234) propose a cost of excess stock due to lost demand, but this cost will be covered with inventory performance cost in the next chapter. Drawn from this insight, the cost components of lost sales and delayed sales is expressed as follows in simplified manner:

Lost sales impact = (Sales rate * Business recovery time – Inventory available)
* (Sales margin per unit + Penalty cost of no delivery per unit)

Delayed sales impact = (Sales rate * Business recovery – Inventory available)
* Penalty cost of delayed delivery per unit

The literature of SCRM present wide set of *general cost components* related to the supply chain risk impact. Cost components more related to specific type of impact are presented in next chapters. Hendricks and Singhal (2003; 2005a, 696) present the related cost components of expediting cost, premium freight cost, additional marketing cost, increased amount of transactions, overtime working, increased need for warehousing and moving of products via logistics costs. Tuncel and Alpan (2010, 256) add the cost of cancelling orders to supplier base and Norrman and Jansson (2004) emphasize the importance of insurance premiums. Bogataj and Bogataj (2007, 292) highlight the cost of currency fluctuations in global environment and Liu and Nagurney (2011, 544) take this into account especially in outsourcing risk decision-making. Hendricks and Singhal (2005b, 36) stress that increased risk might lead to higher cost of capital as higher returns are expected by investors. Furthermore, they propose that the cost of acquiring workforce might increase due to risk events as employees might require higher compensation to work in risky environment. Similarly, they propose that suppliers and customer might require additional compensation through guarantees and assurances to do business with more risky partners.

Some authors highlight the cost components of *redesigning and re-allocating the supply chain* due to supply chain risk event. In this context, these costs are considered as risk impact and not as cost of risk mitigation strategies as they are initiated due to risk event, not beforehand. If there is another source available in the supplier base of the chain when one or multiple sources become unavailable due to risk event, the volumes might be re-allocated to more expensive suppliers and fixed cost of relocating production might occur (Silbermayr & Minner 2016, 228; Mori et al. 2017, 90; MacKenzie et al. 2014, 1251). The fixed cost is even more extensive if new supplier is out of the current supplier base and has not been yet validated. Thus, the costs of identification and validation of new suppliers as well as building collaboration and trust emerge (Silbermayr & Minner 2016, 228; Nooraie & Parast 2016, 11; Hoek 2020b). However, it should be noted that purchase price benefits of increased volumes due to learning and economies of scale might moderate these costs especially if the customer has more leverage than supplier in the relationship (see e.g. Silbermayr & Minner 2016, 228). In addition, if the parties of the supply chain disrupted by the risk event will recover, it can be beneficial not to initiate the costs of re-allocation if costs of waiting for recovery through, for example, lost sales are more moderate (see MacKenzie et al. 2014, 1251).

In addition to the financial impact on sales and costs, the *shareholder value* might be affected by the risk especially if the shares of companies of the supply chain are traded publicly. According to Hendricks and Singhal (2003, 503–504) the ability of the company to execute its operations might be considered inadequate if severe risk events occur. Due to this impact on reputation and credibility, the shares of the company might become undervalued in comparison with peers and the cost of capital might increase due to this effect as well. Furthermore, the top management might have to allocate more costly resources to investor relations to increase credibility. The effect of severe risk events to stock returns might be as much as –40 % in the period of one year before and two years after incident is announced to markets as noted by Hendricks and Singhal (2005b, 35).

4.2.2 Cost of performance loss

In this subchapter, the cost components related to the performance of the operations of the chain are reviewed by addressing three dimensions of supply chain performance: the cost of working capital performance loss, cost of delays as well as cost of quality.

To determine the cost components of performance loss in supply chain due to risk event, one potential framework is provided by the concept of *cash conversion cycle* (CCC). According to Tsai (2008, 1032), the CCC includes the components of days in inventory, days in receivables and days in payables. They note that these components are mainly influenced by the lead time for processes, credit periods for suppliers and credit periods from customers. By anticipating changes in CCC components, additional amount of financing needed to run the operations might be evaluated. This increase in financing needed can be combined with the cost of capital and, thus, the cost of decreased performance of working capital can be evaluated (see e.g. Mori et al. 2017, 90):

Cost of working capital performance loss = (Change of inventory + Change of receivables - Change of payables) * Cost of capital

Few additional supply chain costs related insight can be drawn from CCC concept. Firstly, if the payment time to supplier is higher than the sum of process lead time and the payment time of customers, the supplier is financing the operations of the focal company. This can be problematic in supply chain context if the cost of capital for the focal company is more minor than the one for the supplier. Thus, the cost of capital for the entire supply chain might increase. (Tsai 2008, 1035.) Secondly, the changes in CCC components might trigger other risk impacts. For example, longer lead times might increase the risk of forecast error (Tsai 2008, 1035).

The cost components of risk impact related to inventory performance has been discussed more in depth by the literature in addition to the concepts of CCC and cost of capital. Hendricks and Singhal (2003, 696; 2005a, 503–504) note that supply chain risks might lead to inventory imbalances and inventory performance. This is also related to the concept of service level of the supply chain (see Tummala & Schoenherr 2011, 474). If there is too much supply in the supply chain due to risk event leading to unsold stock and increases in inventory, the additional cost is generated, in addition to cost of capital, by markdown costs of obsolete inventory and additional cost of handling inventory (Cachon 2004, 222; Hendricks & Singhal 2005a, 696; Tang & Tomlin 2008, 20; Kumar et al. 2010, 3723–3726; Silbermayr & Minner 2016, 234; Mori et al. 2017, 90). In addition, according to Bogataj and Bogataj (2007, 292) increase in inventory might lead to more expensive insurance policy. Furthermore, Hendricks and Singhal (2005a, 696) note that excess inventory might lead to decreased sales prices. Such case might happen if the inventory must be pushed to markets with more attractive pricing. On the other hand, too little supply and inventory in the supply chain leads to lost sales margins via opportunity cost (Cachon 2004, 222). The cost of this impact was already considered.

Cost of other performance related risk impacts are covered less intensively by the literature. Hendricks and Singhal (2003, 696; 2005a, 503–504) mention the impact on utilization rate and overall productivity of assets of the company. However, this is mostly tied to inventory imbalances by them as well. The impact on product performance has not been mentioned in this context but the risk impact of this performance measure might be more related to the sales impact if attractiveness of the product in the markets is impacted or to the quality impact if the reliability of the product is suffering from the risk impact.

Other categories of cost components that could be categorized inside performance are cost of delays as well as loss of quality. The *cost of delays* or time loss has been included widely in the literature of SCRM. This is well aligned with the principles of TCO as well. Furthermore, the time related measures were already included in the risk evaluation at construction 1. In general level Rice and Caniato (2003, 30) present ways that companies include time in their cost of risk impact calculations. According to them, the cost impact per day of disruption, time it takes for the risk impact to hurt customer and the time it takes for the risk event to lead to insolvency can be used for this purpose.

As noted by Canbolat et al. (2008, 5154–5155), length of disruption influences sales which is moderated by available inventory. Other mentions of similar concepts are resolution time by Tuncel and Alpan (2010, 256) and business recovery time by Norrman and Jansson (2004). Similarly, Tomlin (2006, 655) proposes that the disruption length affects the inventory cost that is carried to tackle the impact on sales. In addition, they note that if the pre-warning is given about the future risk event related to, for example, labor disputes, the additional inventory might be able to be built to supply chain. This, again, increases the inventory cost but reduces the cost of lost or delayed sales. Thus, the relevance of detection time is distinct. Furthermore, as proposed by MacKenzie et al. (2013, 1251), the recovery time of the source impacted by disruption effects influence whether costs of re-designing or re-allocating the supply chain are triggered.

Canbolat et al. (2008, 5154–5155) further contribute to the insight about cost impact of delay by including the impact of delayed launch of products due to risk events in prototype phase of the life cycle to their study. Here, the cost impact is created by the lost sales as well. Finally, the risk impact on lead time has effect on cost of capital related to CCC as well as costs of transportation and warehousing in general (Tsai 2008, 1032; Kumar et al. 2010, 3723–3726).

Another widely covered theme of risk impact cost is *cost of quality*. Kumar et al. (2010, 3723–3726) mention the cost of decreasing yield as one of the components of both supply cost and cost of production. Thus, if the yield is decreasing, the additional cost for the supply chain is generated. Similarly, Franca et al. (2010) mention the cost of scrapping and reworking material and products. The time impact of quality issues is stressed by Tuncel and Alpan (2010, 256) by including the reworking time of defects in their SCRM simulation model. Furthermore, Canbolat et al. (2008, 5154–5155) propose to include the warranty cost in the cost impact of risk by calculating the estimated customer returns per 1000 products multiplied by the cost of repairing.

For more in-depth evaluation, Pattanayak et al. (2019) propose a classification framework of components of cost of quality. The classification includes cost of prevention, cost of defective inputs, cost of defect in process and finally cost of defect in output. Cost of prevention can be excluded from the analysis as they are not generated by the risk event. Cost of defective inputs include the purchase costs of defective material, cost of processing of the rejection, complaint and return, cost of inventory for defective materials, and cost of shortage. Cost of defect in process contains extra labor cost due to non-standard operations, inspection costs and costs of downtime and maintenance. Finally, cost of defect in output contains costs emerging if the defect is inspected before customer shipment, including inspection and scrap, and the costs if the defect is inspected by customer, including reputation, and replacement. The warranty costs mentioned by Canbolat et al. (2008) are related to the latter class as well.

4.2.3 Cost of resource loss

Cost of impact to resources of physical, social, and psychological loss as well as loss of information and environmental resources have been identified as an effect of supply chain risk events. However, these themes have seen surprisingly low level of coverage by the literature of SCRM.

The coverage on effect on physical resources of the supply chain including property or equipment were not spotted from the literature. However, as mentioned previously, if such impact is considered to occur, the physical resources are included in the book values on the assets of the company and these book values or estimated real values can be used as a reference for impact estimates. The physical loss due to quality will be addressed in the next subchapter 3.2.4.

The cost of social loss due to supply chain risk has been closely tied to loss of reputation and credibility by the literature. If the reputation of the company is impacted and customers become dissatisfied by, for example, lack of availability of products and services, the sales might be lost and company might have to use resources for public relations to recover (Hendricks & Singhal 2005a, 696). The loss of reputation is also related to the increased cost of capital and reduced shareholder wealth as well as increased cost of investor relations (Hendricks & Singhal 2003, 503–504). Furthermore, any direct mentions about the cost of impact on health and safety were not discovered from the literature.

In addition, the cost of psychological loss on self-perception about company or supply chain was another theme that was not covered by the literature of SCRM. This might be logical as this type of impact seem to be highly subjective and qualitative in nature.

For the last two types of risk impact, *information loss* and environmental loss, the mentions about the cost on the literature of SCRM seem to be narrow. According to Durowoju et al. (2012, 1000) the disruption affecting the information flow might lead to increased inventory, backlog and ordering costs as well as hurt the reputation and lead to regulatory fines. Drastic effect on sales has been proposed by the literature as well (Munoz & Clements 2008, 30). For the *environmental loss*, the cost for the supply chain might emerge from regulatory fines as well. The cleanup costs might also be relevant especially in large cases of pollution like the oil spill of BP in 2011. (NYTimes.com 14.9.2011; Hajmohammad & Vachon 2016, 51.)

Based on the literature of SCRM, the wide set of cost components related to supply chain risk impact can be identified. Some of them are interrelated to each other which extends the logical chains related to evaluation of total cost of risk and enforces the holistic and comprehensive approaches of SCRM and TCO. Furthermore, the aspect of time is related to multiple cost components of risk impact directly by the loss of time or by the increasing effect of recovery time for the cost of risk impact. The incorporation of time to the cost assessment is another aspect supported by the SCRM and TCO principles. However, the difference in level of coverage of different components is notable. Thus, lot of gaps to fill are left for the empirical study. In addition, the principle of Knemeyer et al. (2009, 148–149) to focus first on the impacts which are more quantifiable first and then adjust the more qualitative ones can be followed to support the assessment.

The identified cost components of supply chain risk are not illustrated separately based on the literature review. However, the final cost component list based on the empirical testing can be found from Appendix 4.

4.3 Formulation of construction 2: Total cost of supply chain risk tool

4.3.1 Motivation

The second construction of the thesis, total cost of supply chain risk tool, will be developed to assess the monetary impact of supply chain risk. The aim of the construction is to support the three main reasons for measuring the impact of risk: cross-functional understanding of risk consequences, prioritization of risks as well as justification for supply chain risk management resources addressed (see e.g. Hendricks & Singhal 2005b, 36; Knemeyer et al. 2009, 148–149; Kwak et al. 2018, 383).

The logic of Rice and Caniato (2003) is followed in the construction on main utilization of monetary values. According to them, the justification for SCRM resources is most influential when the business case of impact of risks is presented in monetary terms. Similarly, Hendricks and Singhal (2003, 519) stress the importance of providing evidence about the value of losses due to supply chain risks. These ideas are well aligned with Norrman and Jansson (2004) who propose to use measures that resonate to people responsible of business decision-making.

Harland et al. (2003, 52–53) propose usage of mutually agreed measurement systems for risk assessment. In addition, Knemeyer et al. (2009, 148–149) suggest focusing on quantifiable risk impact first and then adjust the assessment based on qualitative items. Thus, the characteristics mutually agreed and quantifiable approach is aimed to be respected by construction 2. However, the qualitative judgements are not entirely abandoned by the construction 2 especially due to the expert judgements used for time-related assessment of risk in Construction 1 and non-qualitative types of impact.

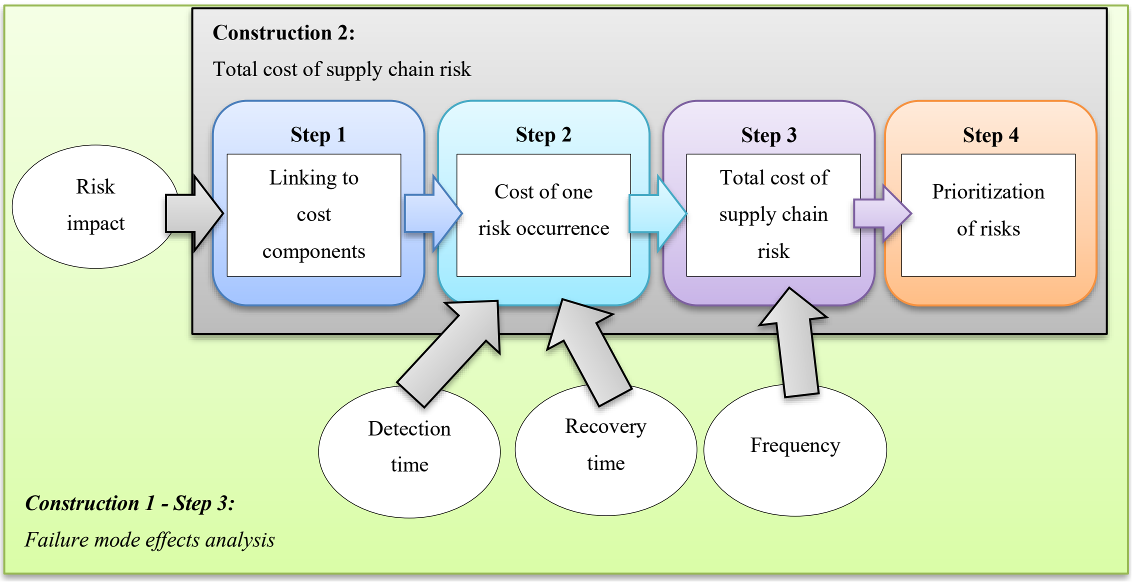

Figure 6. Steps of Construction 2.

The construction 2, total cost of supply chain risk tool, contains four steps of analysis which are presented in the next four chapters. Special notes about implementation of model especially originating from the literature of TCO are reviewed on chapter 4.3.6. Finally, the construction is theoretically evaluated against design principles of SCRM constructions in chapter 4.3.7. The steps of construction are illustrated on figure 6.

4.3.2 Step 1: Linking of FMEA to cost components

The starting points of the construction are the supply chain failure modes and logical chains identified in steps I and II of construction 1 and preliminarily analyzed in FMEA exercise of step III. Firstly, the identified risk impact related to different failure modes will be linked to different *cost components* of risk impact identified via the conceptual bridge provided by the types of risk impact. The focus on wide set of cost components including direct and indirect cost is related to the holistic approach of TCO (see e.g. Hasan et al. 2020, 26). However, to limit to burden of analysis characteristic for TCO, prioritization of cost components will be conducted. The output of step 1 is the FMEA list of failure modes linked with cost components to assess impact of individual failure mode.

Inspiration for the implementation of this step will be taken from literature of TCO. As one stage of a general implementation model for TCO approaches, Ellram (1993a, 53–54) propose the identification of relevant costs for evaluation in the application of TCO.

Firstly, the team applying the TCO model should identify the costs that are relevant for the application area of the model. In the context of construction 2, the application area should be the general context of the industrial and market environment the applying entity is operating in. This could enable wide applicability of the construction. To support the identification, Ellram (1993a) proposes usage of, for example, brainstorming, standard checklists, and cause-and-effect diagrams. In the context of construction 2, the standard checklist of cost components identified from the literature could act as a starting point.

Secondly, from the list of relevant costs Ellram (1993a, 53–54) proposes to identify the critical costs to limit the amount of analysis needed. According to her, the critical costs are not similar in all the buys. Thus, in contrast to the more general identification of relevant cost components, the criticality selection should be conducted for the specific supply chain context under analysis. This is important when compared with the problem of high resource need for the usage of TCO models (see e.g. Ellram 1994, 175–176; Ellram & Siferd 1998). Ellram (1993a) proposes usage of Pareto approach, by assuming that 20 % of the cost components lead to 80 % of total cost. Team approach is proposed by her as well. In the context of Construction 2, the identification of critical costs from the list of relevant costs is conducted by linking the identified risk impact of failure modes of FMEA to critical cost components as per the type of impact on a team exercise. The Pareto approach is utilized by linking only the cost that is assumed to be significant.

4.3.3 Step 2: Cost of one risk occurrence

Secondly, the *cost of risk impact of one risk occurrence* is assessed by evaluating the cost of impact of related cost components in specific supply chain context in terms of both direct and indirect cost. Inclusion of both types of cost is driven by the list of relevant cost components from step 1 which were linked to failure modes on step 2. The consideration of both direct and indirect cost is, as well, related to the principles of TCO approach (see e.g. Ferrin & Plank 2002, 29). The output of step 2 is the list of FMEA failure modes with evaluated cost of one risk occurrence.

To evaluate the cost of one occurrence of risk impact, *adequate data must be gathered*. Ellram (1993a, 53–54) propose that after identifying the relevant and critical cost, the way of gathering data for the assessment of cost must be determined. The difficulty and cross-functionality of the task are emphasized by her. In addition, she stresses that if some data is too difficult to gather, decision must be made whether gathering the certain data returns value.

Berle et al. (2013, 255–257) reviews ways to gather data for the risk quantification from the perspective of SCRM and vulnerability assessment. Usage of historical data is popular in, for example, engineering. However, lack of capability to conduct experiments in controlled environment might limit the utilization in SCRM context according to them. Other limitations for quantification of risks stated by them are interconnectedness and number of risks present in supply chains. Berle et al. suggest that expert judgements can be used for quantifying risk as well, if lack of historical data, interconnectedness or high number of risks are present. The problems of judgments are especially their subjective nature, which can be moderated only to certain extent with structured way of working and, for example, average of assessments. The evaluations of frequency, detection time as well as business recovery time on Construction 1 were already based on the usage of expert judgment. Finally, Berle et al. propose that simulations can be used to quantify risks in complex supply chains with limited historical data as well as support the cost-benefit analysis with risk mitigation measures further on the process. The usage of equations and formulas for assessing the cost in TCO implementation model presented by Ellram (1993a, 54) seem to be related to the usage of simulations. Furthermore, Ellram (1995, 21) propose the usage of ‘conservative convention’ for cases with limited historical data about, for example, new supplier. In this case, the performance of the current supplier with the worst performance can be used for reference. In addition, estimates and other information gathered externally can be used in these situations with lack of historical data.

In the context of construction 2, the team applying the construction must decide as per cost component whether to use historical data, expert judgment, simulation, or other reference data via conservative convention to assess the risk monetary impact. Furthermore, if certain risk impact is considered too qualitative for monetary qualification the principle of Knemeyer et al. (2009, 148–149) to adjust for quantifiable measures as per the qualitative impact if the effect is considered significant can be followed. Nevertheless, it might also be valuable to have a written note about the anticipated qualitative impact for holistic evaluation.

As the cost data is collected, to evaluate the cost of one risk occurrence, the effect of the two *time measures* evaluated on construction 1, speed of detection and business recovery time, must be taken into account. Hendricks and Singhal (2003, 519) emphasize that both time to detect the risk event as well as time to resolve and recover from the risk event increase the impact of risk impact. According to Norrman and Jansson (2004) Ericsson analyses the risk impact via the business recovery time. Similarly, Simchi-Levi et al. (2015, 377) state based on findings from Ford Motor Company that the risk impact is not depending on the cause but more about the duration of risk as multiple risk sources or causes lead to similar kind of impact. Likewise, Tuncel and Alpan (2010, 254) measures all the risk impact in terms of delay, cost, or both as profit.

Practical implication of the relationship of impact and recovery time was provided by Canbolat et al. (2008, 5154–5155) who propose that the cost of delay is created through lost opportunity cost of sales during the delay duration. They also note that the amount of inventory in the supply chain moderates the cost so this measure might be needed to evaluate for the cost evaluation as well in addition to rate of sales and profit margin of lost opportunity cost. The penalty cost of delays or unsatisfied demand can also be considered (see Silbermayr and Minner 2016, 234; Sawik 2015, 60). A bit similarly, Kenyon and Neureuther (2012, 161) propose to compare the recovery time and time it takes for supply chain to lose its competitive advantage due to impact of risk event. Furthermore, Simchi-Levi et al. (2015, 378, 387–388) utilize the estimation of time-to-recover for each step of the chain to estimate and minimize the loss of profit, sales, and produced units due to risk event. In addition, they use the measure of time-to-survive to evaluate how long supply chain can manage after risk event without losing demand. All these viewpoints are related to the cost of impact on sales so similar effect of time measures to other cost components are encouraged based on the literature proposals of magnifying effect of recovery time.

Furthermore, the impact of speed of detection proposed by Manuj and Mentzer (2008b, 196–197) as one of risk components should be tested in empirical setting when the construction is applied as mentions in other practical settings seem to be narrow in the literature. Similar proposal for further research has been provided by Wu et al. (2007, 1860) who stress that prompt detection of risk event enables proactive measures to redesign the supply chain and, thus, mitigate the impact or even avoid the disruption.

In addition to collecting the data to evaluate the cost of one risk occurrence and considering the speed of detection and recovery time, the applying team should take necessary *documentation actions* of data collection as stressed by Ellram (1993a, 53–54). According to her, documentation should cover the used sources of data, is the data based on subjective evaluation or historical data, equations, and results of equations. She adds that the list of updated data sources can be established to support the documentation. This approach can possibly be linked to the standard list of relevant cost components of risk impact. These documentation efforts might enable the preferable state that the parties applying the construction does not have to 'reinvent the wheel' every time.

4.3.4 Step 3: Total cost of supply chain risk

After the cost of one occurrence is evaluated, the *total cost of risk impact* will be assessed by multiplying the cost of individual occurrence of risk impact with the times the risk is evaluated to occur on the entire life cycle of products or services supplied by the supply chain based on the frequency assessed on FMEA exercise. The consideration of risk impact cost through the entire life cycle receives inspiration from the risk evaluation model of Canbolat et al. (2008, 5159–5160). In their model, the impact of risk is evaluated on 5-year phase of time to include the effect of learning and training. Furthermore, the usage of life cycle costs is in the core of TCO approach as well (Ellram 1993b, 4). The output of the step 3 is a FMEA list of failure modes with the total cost of risk impact through the life cycle of products supplied by the supply chain.

To the simple formula of cost of one occurrence times occurrences during the entire life cycle, certain adjustments can be made. Firstly, Canbolat et al. (2008) suggest including the learning to life cycle costs of risk impact. This is done by assuming an annual reduction in impact of certain selected risk scenarios where learning is expected to happen. For example, they mention that supplier might be able to reduce the impact of defective parts, failures due to change management in specifications as well as quality defects on a yearly basis. Secondly, the literature suggests that it might be beneficial to calculate net present value for the risk impact especially if the comparison is made to risk mitigation investments (Berle et al. 2013, 257). Drawing from these points of insight, it should be evaluated during the testing of construction 2 whether learning is happening in the supply chain without further risk mitigation activities in order to justify the adjustment of total cost of impact. Furthermore, it should be evaluated whether the usage of net present value of total cost of risk impact is matching with other supply chain reporting.

4.3.5 Step 4: Prioritization of risks

Fourthly, the *prioritization* of risks will be provided by sorting the failure modes with the total cost of risk impact. This, again, is inspired by utilization of cost of risk impact for prioritization of supply chain risk by, for example, Canbolat et al. (2008) and Norrman and Jansson (2004). Similar kind of approach is taken by Simchi-Levi et al. (2015, 377) who identify which nodes in supply chain pose the greatest risk to supply chain. However, in construction 2, the interest is more on specific risk scenarios due to the cause-and-effect analysis logic used in construction 1. Output of step 4 is the prioritized FMEA list of failure modes as per their life cycle impact. This output can be used as a basis for prioritizing which risks to mitigate, justifying the cost of risk mitigation as well as creating cross-functional understanding of the magnitude of risk (compare with e.g. Hendricks & Singhal 2005b, 36; Knemeyer et al. 2009, 148–149; Kwak et al. 2018, 383).

The step 4 is strongly influenced by the way of working applied by Ericsson. In their model, the risks are prioritized based on the 'business interruption value' (BIV) which includes the gross margin, business recovery time and other related costs from more quantitative end like inventory carrying to more qualitative end like goodwill (Norrman & Jansson 2004). However, certain differences occur. The construction 2 aims to consider the life cycle impact thought frequency as well as speed of detection. In addition, the probability of occurrence is not included in the constructions while the model of Ericsson places the risks into matrix considering both impact and probability. Similarity is that probability is found as problematic concept by Norrman and Jansson (2004) and consequences are valued over the probability in prioritization.

Furthermore, certain inspiration to step 4 of construction 2 is taken from the approach of Canbolat et al. (2008, 5156) from global automotive model for quantifying risk impact. Similarly, the models are used to rank the risks as well and assessing the monetary total risk. Furthermore, the life cycle perspective to risk as well as the basis on FMEA framework bind these approaches together. However, the approach of Canbolat et al. is more integrated into the planning of different mitigation activities whereas construction 2 is only designed to support this activity to limit the scope of the thesis project. In addition, their model is entirely based on simulations, which are more on supportive role on construction 2 due to holistic cost component evaluation approach of TCO as well as the resource limitations of thesis project. Furthermore, the probabilities are more in the center of their model in contrast with the approach taken in the constructions.

To extend the analysis and insight provided by construction 2, certain additional analyses proposed by the literature of SCRM can be made. Firstly, Berle et al. (2013) proposes that certain 'risk acceptance criteria' can be determined in terms of, for example, financial loss, time loss and loss of production. These can be used to compare the anticipated risk impact to accepted level of risk for spotting critical deviations. Secondly, Ellram (1993a, 53, 55) propose fine-tuning the TCO calculations with sensitivity analyses if significant uncertainty for cost components occur and, for example, ranges have been used for evaluations. Thirdly, both Kleindorfer and Saad (2005) and Hou and Zhao (2020) consider the cost of risk assessment process in their SCRM models. According to them, it might be important to evaluate the cost of assessment against the cost-benefit analysis of risk mitigation activities so that the cost of assessment does not exceed its benefits from improved risk management. Finally, Vanany et al. (2009, 25–26) suggest the usage of visualizations in forms of matrixes or diagrams for communicating the risk. They also recommend the usage of 'traffic light analysis' by Norrman and Jansson (2004) where the risks are colored based on their criticality. The relevance of these four additional points of analysis might be tested in the empirical context as well.

4.3.6 Implementation recommendations from TCO literature

The literature of TCO provides set of recommendations for implementation to TCO models. These might prove to be valuable in the testing of the construction 2 due to its connections to TCO concept.

Ellram and Siferd (1998, 72) propose a framework of means to defeat the obstacles of implementing and utilizing TCO approach. Firstly, they stress the importance of providing training and support for implementing parties and, thus, creating understanding of the TCO. Similarly, Ellram (1994, 185, 188) emphasize the importance of training the organization about ways of using as well as benefits of TCO. Furthermore, according to them, training should aim to create understanding of how important items TCO model should be applied for and how to apply the model. Drawing from these conclusions, the training materials for model implementation should be generated for the construction 2 when taken into use.

Secondly, Ellram and Siferd (1998, 72) highlight the significance of 'developing the right model' which is flexible, continuously improved, user-friendly as well as proven enough before implemented to wider use. Similarly, Ellram (1993a, 72) include continuous development of model after testing by linking it to systems as well as updating it and following up its utilization. Inspired by these viewpoints, flexibility, and continuous improvement of construction 2 should be ensured especially by developing the cost component list, user-friendliness should be considered and testing in few supply chains with high criticality should be conducted before wider release. Ability to link the model to systems as a potential development activity should be considered as well.

Thirdly, model should not just be 'right' but also applied to right places. Ellram (1994, 187–188) note that the criticality of the items and sourcing categories should be rather high related to, for example, strategic significance, cost, or experienced problems, where TCO is first applied. This can be ensured with standard criteria or consideration of implementing party. After more experience of TCO has been gained, the model can be implemented to new areas with lower criticality level. Similarly, Ferrin and Plank (2002, 23) note that TCO is first utilized for purchases not done regularly, and Ellram (1993a, 53) include determining the area of utilization as one part of TCO implementation process. Based on these insight, formulation of criteria for criticality of the supply chain of decision-making situation where construction 2 is applied should possibly be considered.

Finally, Ellram and Siferd (1998, 72) emphasize that support for the models should be achieved from right people by, for example, development of model by implementing team, acquiring top management support, and using the success from the first cases for selling the model. Co-operation and cross-functionality are mentioned as success factors of implementation by Ellram (1993a, 53; 1994, 188) and she includes the team-building in the TCO implementation process. Drawn from this insight, cross-functional setting should be used for construction 2 testing and development as well as for further utilization. Ways of finding the support from management should be pursued as well by developing team especially if resource need is found to be requiring it (see Ellram 1994, 188).

4.3.7 Theoretical evaluation of construction 2

In this final chapter of the literature review, the construction 2 formulated based on the insight from the literatures of TCO and SCRM will be theoretically evaluated against the five design principles of SCRM tools. This evaluation provides preliminary anticipation on the usability of the thesis on empirical contexts of the supply chain cases of the client company. Finally, set of alternative methods of risk impact evaluation not included in construction are briefly presented to further strengthen the design decision made. The design principles and coverage in construction 2 are summarized on table 8.

Table 8. SCRM construction design principle coverage of construction 2.

#	Design principle	Coverage in construction 2
1	*Holistic approach*	Direct and indirect cost Time-related measures
2	*Business-oriented quantification*	Monetary approach Time-related measures
3	*Proactive approach & lessons learned*	Assessment of potential future risks Usage of historical data
4	*Cross-organizational approach*	Cross-functional way of working
5	*Industrial context*	Cost component relevance in context

The first design principle for SCRM tools, the holistic approach for supply chain and components of risk, is supported in construction 2 by taking direct and indirect costs and the time-related measures of speed of detection and business recovery time into account on assessing cost of one risk occurrence as well as the measure of frequency on estimating life cycle costs of the risk. Furthermore, by considering the effect of learning, net present value, life cycle phase of the products as well as cost impact on other SC parties than focal company can further deepen this connection if included in the final construction implemented. For latter two, the cost components included in standard listing determines the level of inclusion.

The second design principle, quantification, and measurement with business-oriented manner, is supported in construction 2 by prioritizing and focusing on evaluations in monetary terms. Furthermore, the time-based measures supporting the monetary assessment further support the business-oriented approach (see Norrman & Jansson 2004). However, the more qualitative types of impact included in the construction by adjusting monetary evaluations or as comments are also present in supportive role.

The third design principle, proactive approach, is followed in construction 2 by assessing potential risk in the future. However, usage of historical data to support the cost assessment is aligned with the ‘lessons learned’ approach of the design principle 3.

The fourth design principle, cross-organizational and cross-functional approach, is included in the construction 2 especially by promoting cross-functional way of working. However, need for cross-organizational involvement depends strongly on means required to collect data for linked cost components. Thus, it is possible, that other organizations of the supply chain are not included in the implementation of construction 2.

The fifth design principle, consideration of industrial context, is especially relevant related to cost components. The list of relevant cost components is based on the environment of the company and thus the industrial context is applied. However, due to this flexibility of considering the context of applying company built into the construction, the applicability of the construction is not bound to the context of any specific entity which supports the design principle 5 as well.

The construction 2 takes its greatest inspiration from the work of Lisa Ellram around TCO thinking (see e.g. Ellram 1993a, 1993b, 1994, 1995; Ellram & Siferd 1998) as well as from the excellent automotive SCRM study of Canbolat et al. (2008) related to quantification of risk impact on FMEA framework considering life cycle costs and from the SCRM study in the electronics industry of Norrman and Jansson (2004) considering the prioritization of risks based on time and cost. However, as with construction 1, none of the steps used in a construction are one-to-one replications of any proposed tools by TCO or SCRM literature and, thus, the validation is appointed to general idea of tools rather than internal logic of specific tools. Furthermore, set of theories for quantification and prioritization of risk presented by various authors from the fields of SCRM and TCO are neglected in the formulation of construction 2 for various reasons. The following list is not meant to be complete but rather provide such examples.

Firstly, the prioritization of risks based on objective priority proposed by, for example, Gaudenzi and Borghesi (2006) using analytic hierarchy process (AHP) for the operation was neglected as the monetary evaluation is used as the main prioritization base in the construction 2. The different scales of, for example, 1 to 5 in evaluation used by various authors (see Vanany et al. 2009, 25–26 for review) were neglected from the same reason. The set of purely mathematical methods like linear programming, DA_NETs and mathematical modelling were neglected to avoid unnecessary burden of implementation as well as due to resource limitations of the thesis project and author of the thesis (see e.g. Bogataj & Bogataj 2007; Wu et al. 2007; Ruiz-Torres et al. 2013). Some other models like 'Value-at-risk' concept and Monte Carlo analysis were neglected due to their strong emphasis on probability and probability distributions (see e.g. Sanders & Manfredo 2002; Canbolat et al. 2008; Sodhi & Tang 2009; Pattanayak et al. 2019). These have been intentionally avoided in the constructions due to findings of, for example, Norrman and Jansson (2004) about the usability of probability evaluations. Finally, the most in-depth TCO application quantifying risk in monetary terms, risk-efficiency-based supplier selection (REBaSS) by Micheli et al. (2009), was largely neglected due to its focus on supplier selection as well as tight alignment with risk management strategies which were both out of scope of the thesis. However, to deepen the understanding about the narrow field of literature especially if supplier selection decision-making is relevant, familiarization with the study of Micheli et al. is encouraged. Finally, the viewpoint presented by March and Shapira (1987, 1408) that the quantification of multi-dimensional construction like risk into 'single quantifiable construct' would be undesirable by managers was neglected as a strong field of risk quantification literature has emerged afterwards.

Based on the theoretical evaluation of construction 2 in comparison with the design principles for SCRM tools as well as brief overview of other risk prioritization and quantification theories, the construction 2 is found to fulfil the requirements of SCRM constructions for the testing and development at empirical study at least satisfactorily. The largest deviation was related to the possible lacking inclusion of external parties at the applying of construction which is largely depending on the required data for evaluating cost components as well as the anticipated cost-benefit of such data collection.

5 METHODOLOGY

In this chapter, the methodological background and decision-making of the empirical study are presented and justified based on the academic literature and realities of the empirical work in the Client company. In chapter 5.1, the main frameworks and paradigms related to research approach of the thesis, namely qualitative, and constructive research approaches, and extensive single-case study, are presented, and justified. In chapter 5.2, the research process and the steps taken in the empirical study are presented based on the 7-step constructive research process by Lukka (2000). In addition, the case company and supply chain cases are presented in this chapter. In chapter 5.3, the basis for evaluating the research quality of the study is laid especially based on the guidelines provided by Kasanen et al. (1993). Finally in chapter 5.4, the ethical considerations of the study are reviewed based on the guidelines of the University of Turku.

5.1 Research approach

The empirical study was conducted as a qualitative and constructive study where the initial constructions of supply chain risk impact identification and total cost of risk formulated based on the literatures of SCRM and TCO were tested and further developed in the extensive single-case study in the 'Client' company. The frameworks behind this research approach are further presented and their selection is further justified in the following subchapters. The implementation of the approach is presented in the review of the research process.

5.1.1 Qualitative approach

The first decision in research approach utilized is made between qualitative and quantitative research approaches. According to Eriksson and Kovalainen (2008) the qualitative research approach is usually chosen for research settings where the research study is sought to be understood or interpreted more profoundly. The qualitative approach is usually more holistic and context sensitive as well. The quantitative research approach is more often selected when phenomena are sought to be explained, hypotheses are tested, or statistical analysis is conducted.

In this study, the *qualitative* approach was chosen as an approach. Firstly, this decision was made as qualitative research can be beneficial when the research is conducted on subjects from which there is no extensive knowledge available (Eriksson &

Kovalainen 2008). This seems to be the case especially related to the application of TCO to supply chain risk management. However, it is fair to note, that many aspects of SCRM such as risk impact identification and focusing on risk impact cost on supply chain risk analysis have seen wider coverage in the literature.

Second justification was related to the context-specific nature of qualitative research: the qualitative approach seemed to be especially capable to address business phenomena in their own context (Eriksson & Kovalainen 2008). The context of the Client company, cases and the industry are important in the research design and guides the generalization of the results which seem to provide a suitable match with the approach.

Third justification was based on the holistic understanding sought via qualitative research (Eriksson & Kovalainen 2008). The complex nature of the SCRM and the comprehensive approach taken with wide set of risk components and wide viewpoint of cost originating from TCO approach seemed to be calling this kind of more holistic approach instead of more general level analysis of extensive analysis samples. Furthermore, the focus on testing and developing the constructions with high level of commitment from both researcher and target organization seemed to limit the extent of sample available for the study (see Lukka 2000, 4–5).

5.1.2 Constructive research approach (CRA)

The constructive research approach (CRA) refers to methodological approach and way of executing field research where problem-solving is conducted via innovating constructions which can be for example models or plans (Kasanen et al. 1993, 243; Lukka 2000, 2). The approach has seen wide usage in, for example, mathematics, technical sciences, and medicine (Kasanen et al. 1993, 243). In business studies, the approach has especially been considered and applied in the field of management accounting where the motivation for the approach has especially emerged from re-establishing relevance of the research for practitioners (Lukka 2000, 3–4; Labro & Tuomela 2003; Lindholm 2008). However, the approach has been applied, for example, in the fields of process management, procurement as well as TCO (Degraeve et al. 2004; Ihrig et al. 2017).

The characteristics of CRA are not met by all the problem-solving oriented research designs. According to Kasanen et al. (1993) the problem and the solution generated via construction must have relevance in practical terms but also function practically. Furthermore, the construction must be tied to prior theory and contribute theoretically as well. In addition, the construction itself must be novel. Lukka (2000) add that the levels of co-operation and involvement between researcher and target organization are high, and the theoretical contribution is volatile and hard to predict beforehand. Lukka (2000, 3) proposes that the 'ideal result' of constructive research satisfying needs of all stakeholders of the research is managerial problem solved by innovative and implemented construction. In addition, the construction contributes both theoretically and practically. However, they also state that failed testing and implementation in practical level might provide interesting theoretical contribution.

The justification to apply the CRA in the study were especially based on the pursued results expected by both the author and Client company. Firstly, both the development of toolbox for SCRM efforts of the Client as well as analysis about the risks in current or planned supply chains of the Client were expected. This approach seemed to resonate well with the constructive approach as the solutions must have practical relevance and be able to solve practically relevant real-world problems (Kasanen et al. 1993, 246; Lukka 2000, 2). In order to formulate valid tools for the Client, this relevance and ability to 'survive' in real business cases seemed to be required. Furthermore, the testing and implementation of the construction to demonstrate the usability are especially important for the constructive research (Kasanen et al. 1993, 244; Labro & Tuomela 2003, 436). Thus, this testing and implementation of the constructions enabled the analysis of the supply chain cases of the Client company pursued as well.

Secondly, the usage of theoretically based constructions seemed to match well with the idea of creating solutions or tools for the SCRM process of the Client company. According to Lukka (2000, 3) the specific form of constructions is not pre-determined, but they can be anything from simple models to sophisticated management systems. However, the key is that they are invented and not discovered. Furthermore, the testing and implementation of the constructions is vital on demonstrating the usability, scientific value and even truthfulness of the constructions as proposed by Kasanen et al. (1993, 244, 256). In addition, the theoretical contribution by the constructions is another factor demanded from CRA-based study which also differentiates the CRA from action research, another potential approach for this study (see Kasanen et al. 1993, 257). The creation of tools by examining the academic literature as well as testing and developing them further in the Client company context and providing the theoretical contribution via the developed constructions seemed to answer the needs of both Client company and academic community well.

Thirdly, the usage of scientific knowledge was deeply rooted in the Client company, and it was even stated in the management philosophy guidelines of the company. This seemed to be well-matching with the characteristics of constructive research as scientific methods are expected to be applied, the theory connection must be established, and theoretical contribution must be provided (Kasanen et al. 1993, 246, 252–253). This is one the main differences of the CRA and consulting which could have provided contribution to the practical problem as well. Furthermore, Lukka (2000, 3–4) proposes that due to the two-way communication of researcher bringing theoretical knowledge into problem-solving and the target organization providing practical insight into development and testing of the construction the research provides more value for the target organization than more typical observations and surveys. This viewpoint seemed to support the usage of CRA for providing value for the Client while conducting academic research.

Fourthly, as stated by Lukka (2000, 2) the relationship and co-operation between researcher and the target organization are close and the working happens in team-like way promoting learning in CRA. Kasanen et al. (1993, 257) add that the researcher acts as a ‘change agent’ supporting the target organization in the learning. Labro and Tuomela (2003, 435–436) note that the nature of teamwork is not the same in all CRA projects: sometimes the role is mainly on developing model, some other times on gaining acceptance and sometimes in participant observations specially to explain the failures in implementation. This kind of close relationship promoting the use of CRA was expected to be generated as the author had worked for the organization before the project and most of the employees participating were familiar for the author.

Furthermore, research philosophical questions seem to promote the application of CRA in the study when normative research is compared with descriptive or positive research. CRA can be classified as normative rather than descriptive research (Kasanen et al. 1993, 255). In the context of SCRM, according to Fahimnia et al. (2015, 2), the normative research, unlike positive research, tries to explain what should be done to improve the management of supply chain risks rather than what is currently done. By pursuing new way of working for the Client company, developing the process, and reporting the finalized construction, the research design is closer to normative research than positive research which matches the CRA well. In addition, the two research questions are ‘how-questions’ seeking to understand the way to meet a certain end which links the questions to normative thinking.

5.1.3 Extensive single-case study

The method of *extensive single-case study* was selected to meet the demands testing and development of the theory-based constructions. According to Eriksson and Kovalainen (2008), the extensive case study can use cases as tools to test and possibly extend the existing theory. The case itself is not in the center of interest but the utilization of it and, thus, the study is instrumental in nature. This approach seemed suitable with the research design based on CRA. Furthermore, development of theoretical constructions is stated as one of the possible aims of extensive study by Eriksson and Kovalainen (2008).

In addition to the suitability for testing and development of constructions, the case-studies have been usual when conducting research using CRA: According to Kasanen et al. (1993, 257) the case method is usually applied in CRA studies. Lukka (2003, 83) note that the constructive research is an approach the case research can be conducted with. However, Lindholm (2008) argue that the difference of the case study method and CRA is that case study pursues deep understanding about the subject and communicates that while CRA is targeting on improving practices. Thus, they can be seen as alternative concepts as well. However, in the empirical study, the examples of Kasanen et al. and Lukka were followed, and the selection of case study was considered to support the CRA. Furthermore, the research approach was more heavily influenced by the CRA, and the toolbox of case study was used to support its goals, not vice versa.

The selection of single-case study, the Client company supply chain environment being the unit of analysis, instead of multiple-case study were guided mostly by practical realities. Considering the amount of work needed for testing of the constructions, more company cases would have been extremely difficult to handle without additional re-sources and time. The selection of the Client company as the case was mostly based on the good relations and common history with the author. In addition, this decision was supported by the existence of interesting, realized risk incident to provide background information for the development of constructions and suitable supply chains in early phase of the life cycle for the testing of the construction to provide relevant insight for the development process as well as for the Client.

Inside the single-case study developing the constructions in the context of the one company, three supply chains were selected for the study inside this context. However, these supply chains should not be understood as cases of multiple-case study as the results are not primarily analyzed a way that would compare the results between the supply chains. Instead, all the supply chain cases provide additional insight to the development similarly as, for example, multiple interviewees might provide insight for studied case in some other research context.

Of the selected chains, supply chain case 1 was concerning historical supply chain facing severe supply chain risk event and related impact. This 'ex-post' case was aimed to provide historical data of the risk impact faced in the environment to develop the constructions and, thus, present significant variation from the other two cases. In turn, supply chain cases 2 and 3 were concerning existing or planned supply chains and the focus was on potential supply chain risk impacts. These two 'ex-ante' cases were in special interest of the Client due to high significance business-wise as well as representing a novel style of supply chain design for the Client operations and exposing the company to the risks of outsourcing. The combination of different methodologies is proposed by Xu et al. (2020) to justify the managerial insights. This objective can be seen to be partially contributed by utilizing both historical or ex-post risk impact knowledge as well as analyzing anticipated or ex-ante risk environment to develop the constructions. More accurate description of the supply chain cases, and the review of the data collection and analysis can be found from the research process section.

5.2 Research process

The process of the research conducted will be presented in this chapter by following the 7-step constructive research process illustrated in Figure 7. The research process was first presented by Kasanen et al. (1993, 246) with 6 steps. The complete 7-step process, adding the second step of '*examining the potential for long-term research co-operation with the target organization(s)*' was first presented by Lukka (2000). The development of constructive process was further elaborated by Labro and Tuomela (2003, 415–416) who divided the 7 steps into 3 phases of preparatory phase, fieldwork phase and theorizing phase. In addition, they noted that some of the steps are overlapping: Third step of '*obtaining profound understanding of the topic'* is a process that is continued before and during the whole process and, thus, there is dotted line in the ends of the arrow presenting the process scope of the step. Furthermore, the seventh step of '*showing the theoretical contribution*' covers the entire research process with a dotted line for the most part, as the connections to theory should be considered during the entire process according to Labro and Tuomela. Thus, it seems that the most intense working of every individual step is presented with solid line and supportive working with dotted line.

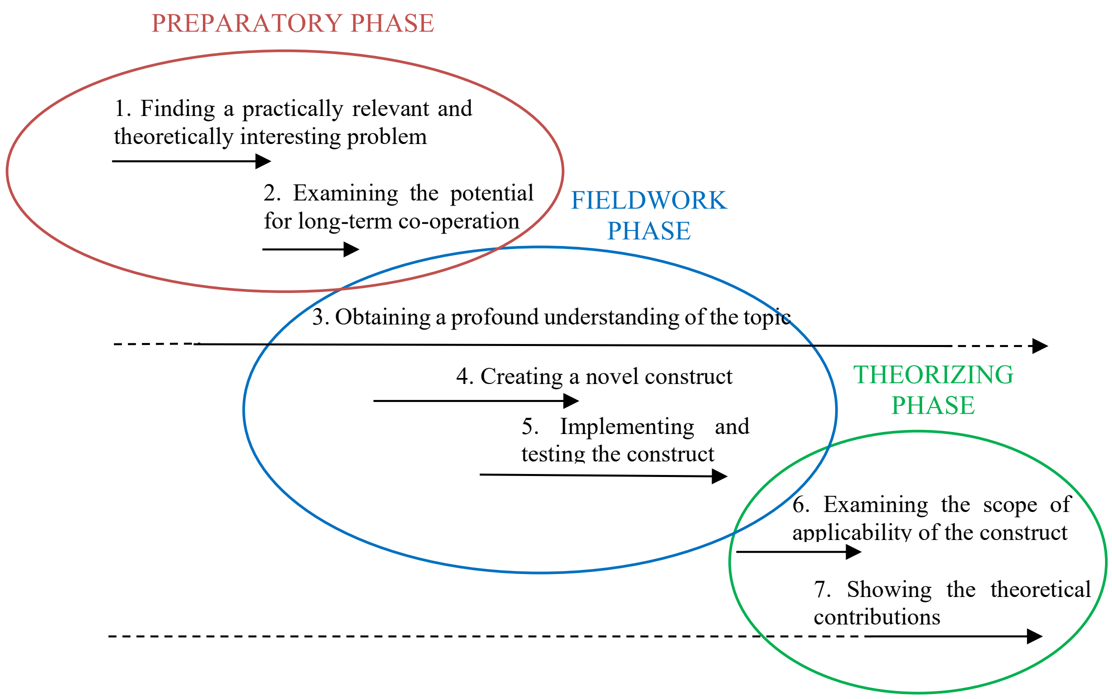

Figure 7. The process of constructive research (Labro & Tuomela 2003, 415).

The process of the research conducted will be presented in the following subchapters from 5.2.1 to 5.2.3 according to the process steps inspired by the example of Lindholm (2008) who use the steps of the process to structure their entire research paper. She notes, that by presenting the constructive research process conducted explicitly, guidance and understanding about the research approach can be provided to reader. However, in this case, only the process will be structured based on the steps, not the entire paper. Thus, the presentation about the literature insight of each of the steps and the way the steps were conducted in this research are presented in the methodology section. However, the actual results of the work especially concerning the finalized construction, applicability to other contexts as well as theoretical connections will be presented in chapters of results and discussion to respect the usual structure of academic reports. This approach resembles the one taken by Ihrig et al. (2017) in their constructive study. Furthermore, the three phases of the process by Labro and Tuomela (2003) will be used to limit the number of subchapters needed for process presentation. In addition, the names of steps and phases presented by Labro and Tuomela will be utilized as they seem to be illustrative and were used by Lindholm in her paper as well.

Finally, it should be noted that especially to respect the needs of the Client company including the tight project schedule the research process was not tightly designed around the 7-step process beforehand, and thus, there might be certain misalignments between the actual process conducted and the process presented by literature. In other words, the 7-step process guides the presentation in this chapter more profoundly than the execution. However, these misalignments are presented as per the specific step they are concerning.

5.2.1 Preparatory phase

Step 1: Finding a practically relevant and theoretically interesting problem

According to Lukka (2000, 4) the first step of constructive research is to find a research problem that satisfies the relevancy needs in practical terms but also provides theoretical contribution. In addition, the construction that responds to problem should be novel according to them and not just an application of construction developed earlier. Labro and Tuomela (2003, 418) add that the original idea can come from the practical need or from research gap. However, it should be ensured that both dimensions are satisfied regardless of the source of the problem. Following the example of Lindholm (2008, 346–347) the process of how the idea for the study emerged and how it was examined from both theoretical and practical perspective will be presented in this step. However, the target organization, the Client company, will be introduced in this step as well, as the selection of the organization was done prior to the decision about the research problem. In this thesis, the results of the step are reported as the practical motivation, research gaps and research questions of the introduction chapter. This respects the usual structure of master's thesis reports in the University of Turku.

Client company is a Japanese owned Finnish company which specializes in sensor technology and serves mostly customers of automotive, industrial, and healthcare sectors. The Client employs over 1000 employees in Finland. Including the parent company, over 70 000 people are employed globally, and the net sales exceeded 10 billion euros in 2019. The author had been working as an employee of the Client for total of 13 months before the assignment which was as well the prime motivator for the co-operation with the particular organization.

The selection of research problem for the study happened in the interface of the practical relevancy and the research contribution: In January 2021, when the co-operation with the Client company in terms of the thesis project was initiated, the preference of the author to conduct the project in the area of SCRM was communicated to the Client company. This was motivated by the bachelor's thesis of the author focusing on the supply chain risks. In that time, the research problem was initially set with two senior-level managers of the Client on the risk identification and risk management strategies in outsourcing activities of the industry. This idea was originating from the reality that the Client had been increasing the level of outsourced manufacturing in its supply chains but also experienced supply chain disruptions and risk events in these supply chains. The tight connection between the outsourcing activities and the risk or uncertainty in the supply chain has been identified by various authors (see e.g. Harland et al. 2003, 51; Vanany et al. 2009, 16; Liu & Nagurney 2011, 539; Tang & Musa 2011, 28–29).

In February 2021, the research problem was further developed by examining the academic literature and preparing the research plan for the university as part of the master's thesis process. In this phase, the research gaps and potential for theoretical contribution was noticed in the area of SCRM cost-benefit analysis involving the cost of risk management strategies and the benefit of reduced risk exposure in monetary terms (see e.g. Sodhi & Lee 2007; Colicchia & Strozzi 2012; Fan & Stevensen 2017; Xu et al. 2020). This idea was discussed with the Client company. The special interest of the Client company was the quantification of risks in monetary terms to justify the decision-making about risk management activities which is main practical motivation of the research stated. Thus, the focus was set on the monetary assessment of risks which was also driven by the concerns about the wide scope if the cost of the risk management strategies would be included as well. Furthermore, the need for identification of risks in the selected supply chain projects of the Client company and development of tools for the risk identification in addition to monetary evaluation of risks was included in the scope. The fit into research context was further developed by author by discovering the connection of supply chain risk quantification to TCO literature which represents the main novelty of the research problem.

In March 2021, the potential research contribution of the problem was examined and established by discovering the four research gaps of the study. In addition, the two research questions of the study were formulated. Furthermore, the practical relevance of the research problem was strengthened by reviewing it with the responsible management group member of the Client and the approval for the research problem was given.

In later phases of the project, the evaluation of contextual factors on electronics and semiconductor industry and around the outsourcing activities were dropped from the center of the theoretical contribution of the research problem to further reduce the workload on the reporting. However, these contexts are still present in the realities of the cases and, thus, they might have an effect of the generalizability of the results.

Step 2: Examining the potential for long-term co-operation

According to Lukka (2000, 4), the potential for long-term co-operation should be reviewed to ensure the commitment from both parties for the research project. The researcher should be member of the project team and the formal agreement between researcher and target organization should be established. In addition to monetary terms and information access, the agreement should be reached especially about the publication of the findings. Labro and Tuomela (2003, 418–419, 422) add that commitment should be built by negotiating and deciding the research problem cross-functionally and with different hierarchical levels of the target organization. In addition, they note that the values of the participants should be considered and availability of resources, especially time, should be ensured. Furthermore, CRA should be introduced to the participants so that the approach and its goals are understood. Finally, the publication materials should be reviewed by target organization representatives for confidentiality and to validate the results. The results of this step are presented in this chapter.

As the research design was involving various different parties in the Client company as well as multiple data collection methods, the commitment of the company was at utter importance similarly as was noted by Lindholm (2008, 347) in her study. Thus, various ways to ensure the commitment and resources were considered.

Firstly, the research problem was validated and innovated with the managers of two different sourcing and supply chain related organizations and further approved by management group level manager. Thus, the idea of Labro and Tuomela (2003) was followed.

Secondly, the agreement about the assignment including the initial schedule and compensation was signed together with non-disclosure agreement (NDA). According to Kaplan (1998, 113–115), the compensation can be utilized to build commitment but criticism towards charging the target organization has emerged from the literature as well (see e.g. Labro & Tuomela 2003, 410). Nevertheless, the compensation for master's thesis working was a guideline in the Client company and favored as well by the Client.

Thirdly, the resources for the project were ensured by communication of the senior-level manager to potential participants to support the thesis project. Furthermore, the supply chain risk analysis of one of the supply chain cases, was included in the scope of one of the cross-functional focus teams (CFT) which specialized in the development and establishment of that particular chain. These teams are named for one fiscal year as a priority project teams working around important business or technical development project and, thus, ensure adequate commitment and resourcing. The author was made a temporary member of the particular CFT as well. The other supply chain analyzed was in crucial phase of ramping up and in wide responsibility and oversight of the senior-level manager. This enabled the sufficient commitment and resources for that analysis as well. Furthermore, bi-weekly follow-up meetings were organized with the two senior-level managers to establish continuous communication with the target organization. The insufficient frequency of communication throughout the process is highlighted as one of the common pitfalls especially for less experienced CRA researchers by Lukka (2000, 12–13).

In addition to creating commitment, the values of the Client organization were found matching the research project. However, in contrast with the usual CRA process, this review was conducted after the empirical phase was concluded and, thus, did not influence the actual decision-making. The match of values was especially true regarding the usage of scientific knowledge which was stated even in the guiding management philosophy of the Client company. Furthermore, the risk management efforts were part of the product development processes and thus the familiarity on concepts of risk and risk management were readily established. There were risk management analysis and efforts taken in the supply chain and strategic business levels as well, but the methods were not aligned.

The confidentiality and publication issues of the public master's thesis report were managed as follows: It was decided that one of the senior-level managers would review the thesis report before publishing for issues with confidential information and that there would be no confidential information included in the thesis. Furthermore, the name of the Client company or any associated companies were decided to be hidden from public report and the focus on the actual report would be on the way of conducting risk analysis, not in the risks and their monetary values in the specific cases. In addition, plan for data management was formulated and communicated for the client company. The main points about confidentiality of the collected information and publication of the thesis were communicated for the participants in the beginning of data collection sessions and email chains as well. In two sessions of one of the supply chain cases, this information was mistakenly not communicated but the information was provided afterwards with possibility to specially limit the usage of information collected in those particular sessions.

Finally, in contrast with the thinking of Labro and Tuomela (2003, 422), the CRA was not deeply introduced to client company. This was a decision done by the author to limit the burden for the participants about the academic side of the process and due to unfamiliarity with Labro and Tuomela's thinking at the time. However, the research process and aims of the project were presented to participants and the potential negative effects of excluding the CRA introduction did not become clear in the process.

5.2.2 Fieldwork phase

Step 3: Obtaining a profound understanding of the topic

Lukka (2000, 5) proposes that the third step of the process focuses on gathering '*profound insight of the original state of affairs'* and problems of the organization conducted with non-interventive methods like observations, records or interviews. In addition, insight from the previous theory of the subject should be gathered for basis of the development but also for reflecting the findings back to theory. Lukka (2000, 5; 2003, 92) highlights that this extensive background work is one of the main differences between CRA and consulting. This view is supported by Labro and Tuomela (2003, 416) who note that both the third step of profound understanding and the seventh step of theoretical contributions continues through the entire study. In addition to background work both empirically and theoretically, Labro and Tuomela (2003, 423–424) note that time assigned for familiarization between the researcher and the target organization is valuable in this step.

The *theoretical background* work continued after the identification of research gaps and questions in March 2021 to examination of academic literature of SCRM and TCO and formulation of first versions of constructions during April and May 2021. For the discovery of academic journals, the database of Volter by University of Turku was mainly used. Database of Scopus was also used as a supportive tool. Some of the most used search terms utilized included 'supply chain risk assessment', 'supply chain risk identification' and 'total cost of ownership'. The main focus was kept on the journals published during 21st century due to the rapid development of the research field of SCRM but the 1990s academic research proved to be extremely rich especially concerning the concept of TCO. The results of this work with prior research are reported in the literature review chapters of the thesis.

As for the *familiarization* between the author and the Client company, the basis was very rich due to the 13-month work history in the company. Owing to this, most of the participants were familiar with the author and had worked together with him. Furthermore, the author had worked under direct supervision of both the senior-level managers championing the project. According to Lindholm (2008) the mutual trust emerging from shared past might ease the creation of understanding about the situation of the target organization. This was very likely in the case, as the author had worked with the supply chain risk management efforts of the company before.

The *empirical background* for the work was conducted by studying the historical supply chain case (Case 1) of supply chain disruption happened during timeframe of summer 2019 to spring 2020 according to the proposal of the Client company. The aim of this study was to increase the understanding of the monetary risk impact and risk drivers present in the context of the Client company. This insight was then planned to be used as a historical data reference for the analysis of the two other supply chain cases and for the development of the constructions. The relevant results of the study concerning case 1 are presented in the results section of the study.

Case 1 was concerning a supply chain disruption where a supplier location of outsourced assembly and testing services of the Client company was shutdown with a very short 3-month pre-warning further extending to 6 months. There was no other validated source available so the validation and ramp-up of other two supplier along with buffer building were initiated. The shutdown happened in ramp-up phase of the production of the first products manufactured for the Client company by the supplier.

The data collection and analysis of the case 1 included four phases with multiple sources of data: (1) semi-structured interviews to gather data about the case, risk impact emerged, and the risk drivers present, (2) group discussion about the data sources for the monetarization of impact identified, and (3) data collection and analysis of the cost data from various sources. The usage of various sources of data usually increases the quality of the case study (Eriksson & Kovalainen 2008).

Firstly, four semi-structured interviews were conducted with different professionals who were directly or indirectly involved with the case. The interviewed persons were from different teams of the Client company and their areas of responsibility covered the planning of supply chain and ramp up, sourcing responsibility of the particular supplier, product management of the client company as well as project management of the products assembled in the closed supplier. The selection of the interviewed persons was aiming to produce cross-functional understanding of the case and the selection was done together with one of the senior-level managers. Semi-structured interview was selected to enable the emerging nature of different themes related to the case (Eriksson & Kovalainen 2008) and the interviews were also recommended for this task by the senior-level manager. The pre-task to think about the different risk impacts and risk drivers present in the case was issued before the interview. Examples of both concepts were provided in the pre-task. In the interview, one and a half hours were reserved for each of the interviews, and they were recorded to enable checking of the information afterwards. The questions of the interview were divided in the theme of background including responsibilities and the course of events, theme of risk impact, and theme of drivers affecting the risk impact. For the last two themes the interviewee first stated their viewpoint about the impacts and drivers and then further of insight was gathered based on the classification of risk impacts and drivers based on findings in the literature review. After the interviews, the insight was coded with preplanned coding based on the classifications of risk impacts and risk drivers used in the interviews already. Preplanned coding was selected as the insight was aimed to be aligned with the classifications used in the constructions as well.

After the interviews, a group discussion between the interviewed persons was organized focusing on the ways of measuring or evaluating the monetary impact of different realized impact. The session was facilitated by the author, and he participated in the discussions as well. The impacts which measuring was found to be too difficult, were neglected. One hour reserved for the discussion was not enough and, thus, discussion was continued in emails and ways of measuring were innovated by the author as well individually. High level of intervention by the author might lead to participant bias as proposed by Labro and Tuomela (2003) but was required to advance the working efficiently.

Based on the group discussion, the data collection about the monetary impact of realized risk from professionals in different teams of the Client company mostly via emails as well as from systems of the Client company was conducted. This activity was as well highly driven by the author. However, the results were reviewed by the relevant company personnel after and, on some occasions, during the analysis. As a result of the analysis of the case 1, list of different risk impacts with the monetary values as well as list of risk sources and drivers of risk impact were formulated and utilized as a reference for the other two cases analyzed as well as to development of the models. The relevant results and their utilization are presented in the results chapter of the study.

Step 4: Creating a novel construct & Step 5: Implementing and testing the construct

The background gathering is followed in the CRA process with *innovation of the construct*. According to Kasanen et al. (1993, 246–247) this process is very crucial on the entire study as there is little possibility to continue if the construction is not created. They also add that this process is heuristic as more profound testing in practical terms and justification in theoretical terms comes usually later. Furthermore, the new construction should provide something new for both practical users and research community. Lukka (2000, 6) agree with viewpoints of Kasanen et al. but also add that the innovation process is creative and iterative but also time-consuming as the steps of innovation, small-scale testing and further development form a cyclical workflow. Furthermore, they note that process should be co-operative and utilize both theoretical and practical background.

According to Lukka (2000, 6–7), after the innovative construction is developed the next step is to *test its feasibility by implementation to target organization*. The idea is to test not only the technical working of the construction but the process as well. They state that this part of the process is very demanding and requires deep commitment from both parties, selling efforts to target organization as well as holistic intervention from researcher to advance the process. Labro and Tuomela (2003, 428–429, 436) add that the teamwork is crucial in the phase to ensure smooth testing, to enable co-operation for implementation as well to increase the validity and reliability of the findings. In addition, they propose that without implementation efforts constructive studies, such as two studies analyzed in their paper, will not reach satisfactory level of credibility.

In the basic CRA process, the steps of creation of novel construct and implementation or testing of it are two separate steps. However, in the constructive study of this thesis, *the two steps were highly intertwined* and thus not easily separatable: the theory-based versions of the constructions were developed in author-centric manner already in the end of the background working. After receiving positive feedback about the general idea of the constructions, the process proceeded right into testing and implementation of the constructions into two supply chain cases of the client company and development of the constructions based on the testing. Thus, the co-operative development step between background work and testing was not conducted as a separate step.

However, there are a number of justifications for this selection: Firstly, the root cause for the mismatch was that the original research plan was not aligned with the basic CRA process in the planning phase. Secondly, the planned timeframe for the project of around 6 months was much shorter than in the usual CRA projects. For example, only the case study included in the CRA project of Ihrig et al. (2017, 221) lasted for a period of two years and the total length of the CRA study analyzed by Labro and Tuomela (2003) was a period of four years. Thus, need for combining process steps of co-operative development of constructions, and implementation and testing to optimize the length of the project seems rational. Thirdly, initial feedback about the constructions was asked from the participating teams in the beginning of the testing round. However, it seemed difficult for the participating teams to provide feedback prior to the testing judging from the low amount of feedback received. Thus, it seemed more rational to collect feedback and develop the model further after the testing. This is supported as well by the iterative nature of the development process proposed by Lukka (2000, 6).

The combined steps of development of the construction as well as testing and implementation to the Client company were conducted with the following process presented in this chapter. The results of these efforts – the finalized construction with development happened in the process and the feedback that influenced the development efforts – are presented in the results section of the thesis.

After planning the logic and general content of the construction 1, supply chain risk and risk impact identification tool, by preparing and writing the thesis chapter 3 and examining the practical problem communicated from the Client company, the general idea of the way of working was presented for the two senior-level managers in one of the biweekly follow-up meetings in the end of April 2021. The feedback for the idea was positive and, thus, the development of the construction was encouraged to continue.

During May 2021, the introduction of the construction 1 was continued by creating the first functioning versions of the three construction 1 steps of risk mapping, cause-and-effect analysis (CEA), and failure modes effects analysis (FMEA). This was a researcher-centric task to advance the process to testing of the construction more rapidly and to save the efforts of the participants to actual testing. This follows the example of Labro and Tuomela (2003, 426) who note that, especially, in the CRA studies aiming to create decision-making tool such as the study of Degraeve et al. (2004) the innovative process might rely more profoundly on the individual work of the researcher. The functioning versions of constructions were built into Microsoft Excel files to enable the familiar working environment for both researcher and company personnel as well as to enable the usage of the peer-working functions of the Client company systems. Reference for the visual interface, terms, and content of the FMEA tool was taken from the FMEA tables used with one of the suppliers of the Client. In addition, the knowledge extracted from the Case 1 was used to fine tune the risk source and risk impact classifications used as a basis for risk impact identification work.

For the actual testing and implementation of the construction 1, as well as the construction 2, two supply chain cases named Case 2 and Case 3 were selected. The decision to utilize these two specific cases was made together with the Client.

Case 2 was concerning a new supply chain for the upcoming product launch in few years. The Client company was aiming to establish more control on the design and supply chain of one of the main components of the product and decided to work directly with two tiers of suppliers: second tier for manufacturing the component as per the design and specification of the Client and first tier for testing of the component. In the other products such supply chains were controlled by the first-tier supplier and the design was usually co-owned. Thus, this represented a new operating model for the Client company.

Case 3 was concerning the same product supply chain than which was hurt by the supplier shutdown in Case 1. The closed supplier responsible of assembling and partially testing the product of the Client company as per the specification and design of the client and using subcomponent manufactured by the Client company was now replaced with dual source of two suppliers. The mass production with one of the products was already started with one of the two suppliers and more products were in the process of validation for the suppliers.

The selection of these two cases was mainly based on the interest of the Client: Both cases represented a change in the usual operations model for the Client. In addition, both were in fruitful early phase in supply chain life cycle which allowed actual risk management actions to be taken more easily than in more established chains. This was especially the case with the Case 2 as the details of the supply chain design and supplier relationships were still deeply in the drawing board. Furthermore, the usage of two cases for the testing of the model was expected to provide more valid results about the practical relevance of the constructions in different supply chain contexts than usage of only one case.

In the late May to early June 2021, the testing and implementation of the construction 1 in the two supply chain cases happened in five 30 to 90-minute workshop sessions per case lasting around five and a half to six and a half hours in total. The sessions were facilitated by the author as a participant with the best knowledge of the working. The workshop method with teamwork was selected to mimic the way the tools would be utilized in the real working as well. This was expected to allow realistic circumstances for testing. For Case 2, the separate kick-off session for presentation and feedback of the way of working was conducted. For Case 3, the kick-off was included in the first working session due to schedule issues. However, for both cases the materials related to the way of working were provided beforehand by email to establish level of readiness for working. Another difference in preparation was that the supply chain map used to assist the risk source identification was formulated in collaborative way in Case 2 but individually in

Case 3. This difference originated from the inclusion of the supply chain mapping in the Case 2 CFT team scope and usage of it in other uses as well. In addition, the Case 3 supply chain was very familiar for the author as he had worked with it intensively before and, thus, it was proposed by the senior-level manager to prepare it by the author individually.

To respect the importance of teamwork in implementation and testing step highlighted by, for example, Labro and Tuomela (2003, 429) teams for the workshop activity were selected with the Client personnel. For the Case 2, the participants were selected from the CFT team responsible of the supply chain development of the chain together with the CFT team leader emphasizing members more oriented to the supply chain issues but still maintaining cross-functional setting. The team was strengthened with logistics manager as one was lacking from the CFT roster, and the strength of the team ended up to five members excluding the author. For the Case 3, a cross-functional team responsible of the validation of the two new suppliers strengthened with another sourcing professional was used for risk mapping. However, for the rest of the steps, narrower team of three supply chain and sourcing professionals included in the validation team was used for the rest of the testing by the proposal of the senior-level manager to limit the amount of workload for the validation team of nine members. These team compositions were used for the testing and implementation of the construction 2 as well with some of the team members absent due to summer holiday season.

In the actual workshop sessions, the tools of construction 1 were tested mainly according to the way of working planned for the construction 1 in the literature review. The changes for the way of working emerged in the process are more in-depth reviewed in the results section as they are one important source for the insight of this research project. The working techniques of brainstorming in collaborative excel files as well the group discussion about the aspects of risk were utilized. In addition to the facilitation, the author participated in the risk-related discussions but with less extent than the actual participants. There was, as a principle, one of the three steps of construction 1 utilized as per session but in some cases more than one session had to be allocated for one step of working.

In addition to the risk insight collected in these sessions, the feedback about the way of working was collected to enable the iterative development process proposed by Lukka (2000, 6) with following ways: Firstly, participants were asked to comment pros, cons and development items about the tools and way of working as per step to collaborative Excel file. Technically, the feedback was not anonymous as the writer was visible in the collaborative file platform while writing and the modifications for file cells were traceable. However, it was assured to participants that the feedback would be treated anonymously despite these technical possibilities. Secondly, the participants were asked to fill a survey with following question: '*How likely I would like to have the [e.g. FMEA] tool used in the session applied in future supply chain risk management work?*' The five-step scale from 1 to 5 were given 1 representing very unlikely and 5 representing very likely. Further explanation of the 'tool' meant in the question was provided in some of the surveys when considered necessary by the author. The open feedback was expected to provide more qualitative feedback about the working to enable further development of the construction while the survey was expected to provide insight for the weak market test proposed by Kasanen et al. (1993, 252) about the willingness to apply the application in the actual working of the target organization.

Consequently to the testing and implementation of the construction 1, the construction 2, the total cost of risk assessment tool, was developed, tested, and implemented in the two supply chain cases of the Client presented earlier in this chapter. As the process resembled the testing of the construction 1 heavily, in the next process description the focus is on differentiating procedures.

In the early June 2021, After the theoretically based version of construction 2 was developed, the idea and general process was presented to the two senior-level managers. Feedback was positive and approval was given to continue for developing the practically usable construction and for testing the construction.

The first practical versions of the construction 2 included the set of total cost assessment columns in the FMEA excel tool used in construction 1 as well as the cost component list to measure monetary impact of different risk impacts identified. The both are presented on the results chapter of the thesis as they are an important piece of insight provided by the study. The former was developed independently by the author by integrating different aspects to assess presented by the academic literature to the FMEA table to meet the tight schedule targets of the work. However, the latter was developed in co-operative one-hour session with one of the senior-level managers and supply chain manager of the Client as the content of relevant cost implications and their evaluation in the context of the Client seemed to especially call for co-operative work already in preparation. The cost component list integrated knowledge about different cost components provided by academic literature, insight gathered from the cost implications of Case 1 as well as the expertise of the participating experts.

In mid-June 2021, the actual testing and implementation of the construction 2 happened similarly as the testing of construction 1 in the co-operative workshop sessions facilitated by the author with the same teams. The main difference was that, as per decision made with the senior-level managers, the author prepared proposals for the risk components, different estimates as well as the calculations of the cost of the risk impact. This was found beneficial as the workshops could focus on prepared discussion of the cost elements and not for making the actual calculations. As a by-product of this decision, the four steps of the construction 2 – linking to cost components, cost of one risk occurrence, total cost of supply chain risk, and prioritization of risks – was not separated as per session but prepared first by the author as a whole and then reviewed by the team. This process of reviewing took three sessions of 60 to 90 minutes totaling four to four and a half hours of teamwork. Some of the review required further clarifications via email and some of clarifying conversations continued to July 2021. The feedback was gathered similarly as was done with the construction 1.

During the testing of the constructions, the author felt that the feedback gathered via open feedback as well as via survey did not provide enough insight, especially, about the actual theoretical proposals and aspects of risk included in the tools to justify theoretical contribution. In addition, viewpoints about the evaluation, scope of applicability and further development needs for the constructions were not in adequate level in the original feedback gathered. Thus, an extra feedback and development session of 120 minutes was organized after the testing sessions in late-June 2021. The technique of the session mostly followed the structured group interview as there were little room for additional questions due to number of themes to cover in limited time with three participants. According to Eriksson and Kovalainen (2008) the structured interviews might suit well to situations with limited time resources. The will to limit the time used for the session after heavy testing process also guided the selection of group interview rather than multiple one-on-one sessions. Participants included members of the teams involved in testing of both construction 1 and 2 which narrowed the number of participants to three due to already started summer holiday season. However, it was decided not to postpone the session due to tight project schedule. Interview questions, summary of feedback already collected, and results of surveys were provided to participants beforehand.

The feedback session focused on four themes of feedback items: Firstly, the relevancy of results, simplicity, and easiness of use of different steps of working were inquired following the requirement for the valid or working construction by Kasanen et al.

(1993, 258–259). In addition, the opinion about the relevancy of different theoretical proposals in the constructions were inquired to have focused feedback about the theoretical concepts. For example, opinion about the usage of time measures and evaluation of risks in monetary terms was discussed. Secondly, as per the process step, the improvement ideas were inquired to support the development efforts. In addition, the areas of suitable use in the Client company were inquired to support the contribution to applicability of the construction. Furthermore, the different theoretical additions not yet tested, for example net present value calculations of risk costs and deeper involvement of life cycle phases in risk considerations, were inquired. Thirdly, in addition to step-specific considerations, opinions about theoretical proposals, and additions common of all process steps were inquired. Finally, to further strengthen the results about scope of applicability of the constructions, the viewpoint about the extent and intensity of the usage of the two constructions was asked to be determined in the evaluation matrix of Labro and Tuomela which will be presented more in depth in the next chapter of theorizing phase.

In the July 2021, the final steps of testing and implementation in the scope of the project were taken. Firstly, all of the feedback collected in the implementation sessions, feedback, and development sessions as well as in other conversations with participants was coded based on the step they were concerning and main nodes – relevancy, simplicity/easiness, theoretical proposals, development items and the scope of applicability to other contexts – preplanned from the feedback themes. The subgroups of nodes, in turn, combined the preplanned and grounded theory as nodes such as different kinds of theoretical proposals were derived from theory and nodes such as different themes of development items were based on the collected data. This combination was done as some of themes covered in the feedback collection enabled large set of different themes and others were more focused to certain concepts such as theoretical proposals behind constructions. Eriksson and Kovalainen (2008) note that pre-planned systematic coding is suitable for theory testing, which is the case with, for example, theoretical proposals. Furthermore, the feedback items were coded as per whether they were for and against the used approach. The feedback items of development items and the scope of applicability were left out of this classification as it did not seem practical for such themes.

Based on the coding of the feedback items, set of development items for the constructions were formulated and implemented to construction if practical. These development items were then reviewed with two of the company participants to validate the results and to allow further feedback about them. After the review, the constructions were altered to their final form in the scope of this thesis based on these final feedback items.

Finally, summaries about the constructions and the risk insight from the three cases were formulated and communicated to the Client company personnel in separate three result sessions to provide the relevant results in an easily accessible form to practical users. Two of these result sessions were provided for the personnel working with the two analyzed supply chains to hand the analysis process over and to communicate results most relevant for them. The third results session was aimed for a wider audience addressing the results on more general level.

5.2.3 Theorizing phase

Step 6: Examining the scope of applicability of the construct

According to Lukka (2000, 7) the last two steps of the CRA process require the researcher to move the focus away from the empirical problem-solving with high level of commitment. Instead, the more objective approach should be taken to reflect the learning process and the results of the process. Labro and Tuomela (2003, 429) tie these last two steps of the process or 'theorizing phase' to examining the external validity of the study.

Lukka (2000, 7) proposes, that the sixth step of the process aims to find out whether the construction produced is applicable and 'transferable' to other organizational contexts especially if anticipated results were generated. However, even if entire or partial failure of the testing and implementation occurs, the contribution can be provided by discussing the reasons of failure that might be relevant in other organizational contexts as well. Lukka adds that the actual follow-up of implementation to other contexts should not be in the scope of the study testing the construction but should be left for the future research.

The concept of weak market test is usually tied to this phase of the CRA process (see e.g. Lindholm 2008). Kasanen et al. (1993, 252) proposes that market tests are based on the idea of examining how well the construction could thrive in the 'market' of the solutions. The first step of the market test, the weak market test, concerns the question whether any of the managers have been willing to apply the construction in the real decision-making situations. The semi-strong market test concerns how widely the construction has been adopted and strong market test concerns whether better financial results have been achieved by using the construction. They note that already the weak market test is difficult to pass, and the two higher levels require large amount of implementation data which cannot be collected in a short time frame.

Due to this difficulty of justifying the truthfulness of the construction above the weak market test, Labro and Tuomela (2003, 430–431) present their detailed version of the weak market test where the actual utilization of the construction is evaluated in dimensions of intensity of usage and extent of usage. Former answers the question of how regularly the construction is used in actual working and the latter answers the question of how widely the construction is used. They state that the weak market test is passed in minimum if the construction is used at least once generating actual actions in the organization. In addition, more often and more widely the construction is used, the stronger the pass of the weak market test is. Rautiainen et al. (2017, 25–26) propose a stricter definition of intensity of usage by considering the 'utilization rate' of the construction. These considerations include questions of whether all parts of the construction are used with same intensity and whether the use is widely accepted, non-questioned, aligned with the control systems of the organization and, thus, institutional, regardless of the regularity.

In this thesis, the step 6 of the scope of applicability is mainly analyzed in the subchapter of discussion and conclusion addressing limitations of the research. The analysis is based on the feedback received in the testing as well as the weak market test framework of Labro and Tuomela (2003).

The data supporting the discussion about the scope of applicability is mainly based on two themes of the feedback and development sessions with the testing team: Firstly, the extent of usability of the constructions of the study was discussed with the participants by asking '*in what areas (e.g. projects, sourcing categories) could the tool be applied to?*'. This question was aimed to provide insight about what kind of areas the construction would be found relevant. Secondly, the participants were asked to anonymously fill a weak market test matrix of the Labro and Tuomela (2003, 430–431) based on the perceived potential of the set of constructions (see Table 9). In addition, the actual intensity and extent of usage as of the writing stage of the thesis was evaluated by the author. The two lowest phases of the matrix of Labro and Tuomela were removed as they did not seem relevant after testing the constructions in two supply chain cases. The evaluation was conducted based on both actual and potential usage as the actual usage was not expected to be revealed during the thesis project due to its length of only 6 months. This approach is close to the weak market test reported by Ihrig et al. (2017, 228) where the 'desired' level of usage was evaluated in addition to the actual stage. In addition, the evaluation was done only for the entire set of constructions including both constructions 1 and 2 as the efforts required from participants was pursued to be limited. The ideas of Rautiainen et al. (2017, 25–26) about the utilization rate were neglected as the aspects proposed by them were considered by the author too difficult to evaluate beforehand.

Table 9. Weak market test matrix (based on Labro & Tuomela 2003).

		The **extent** of usage (how often* used in organization based on potential)				
		One person (personal tool)	Team (e.g. Sourcing)	Business unit (Client)	Division (Parent division)	Entire organization (Parent company)
The **intensity** of usage (how often used in organization based on potential)	Regular use replacing old system(s)					
	Regular use in parallel with old system(s)				Strength of the pass	
	Ad hoc usage	Weak market test passed				
	Used once					
	Tried once but not actually used					Weak market test not passed
	Rejected after Unsuccessful implementation trial					

* Spelling mistake in the table used in the session. Should state widely, not often.

In addition to the feedback and development session, insight about the applicability was collected during the testing with the surveys of scale of 1 to 5 about the will to apply the constructions in future SCRM working. This insight was used to provoke discussion in the feedback and development session, but the results will not be used in this thesis for analysis due to low number – mostly one to three – responses per survey.

Step 7: Showing the theoretical contributions

According to Lukka (2000, 7–9), the final step of the CRA process is to create the connections and synthesis between the findings of the study and the prior scientific knowledge. Again, moving the focus from the empirical work and high-level of commitment to wider implications of the results is of the utmost importance. Labro and Tuomela (2003, 416) add that the seventh step is continuous process and the connections to theory should be taken into account during the entire project even though the actual formulation of theoretical implications would happen in the end.

Lukka (2000, 7–9) suggests that this theoretical contribution is generated two ways in CRA study: Firstly, the construction as a novel concept for an academic literature which is tested in a real business setting forms a theoretical contribution itself. Furthermore, this new way of finding connection between way of doing things and the aims targeted with it might provide ideas for future research as well. Secondly, the fundamental result of the testing of the construction – whether the construction works or not – creates another way of theoretical contribution. The tested construction is based on theoretical proposals about the structure and process related features. Thus, based on the functionality of the construction or lack of it, these proposals get tested as well. Labro and Tuomela (2003, 433–437) agrees with Lukka by proving based on the review of two CRA studies that many kinds of theoretical contribution can be provided with CRA.

Lukka (2000, 7–9) further proposes that this theoretical contribution from the functionality of the construction can happen in the forms of new theory, theory testing and theory refinement. In all cases, the research process must be well managed to generate significant theoretical contributions. According to him, if the construction is based on a research gap of lack of research in certain area, new theories might emerge. Theory refinement happens if an assumption about some relationship between means and ends gets challenged by the study. This can happen if, for example, some tool proposed by academic literature and embedded into construction provides unanticipated results. The theory testing happens if a universal hypothesis is supported or challenged by the study. However, the small sample size sets limitations for this and the testing must be well planned to provide feasible results. Furthermore, Later, Lukka (2003) adds fourth type of theoretical contribution from the functionality – theory illustration. According to him, by being a new application of a prior theory, the theory can be illustrated by supporting the assumptions behind the theory and the practical implications of the assumptions.

In this thesis, reflecting the results back to theory is mostly done in the key findings and theoretical contribution subchapters of the discussion and conclusion chapter. Even though the actual reporting about the theoretical contribution happens in the end of the thesis, the contribution was considered already earlier in the process by, for example, formulating the first version of the literature review and the theoretically based constructions before the testing, implementation and development in the empirical setting to ensure close documentation of and connection between theoretical proposals, constructions based on them and the actual results of the testing of constructions.

The results about the first type of theoretical CRA contribution, the construction itself, is covered in the results chapter by presenting the finalized constructions based on the testing and feedback highlighting the changes to the literature-based constructions and the triggers for changes including the development items proposed by the participants of the testing and development session. The results about the second type of theoretical CRA contribution, the functionality of the theoretical proposals behind the constructions, are based on the feedback received in the testing phase as well as in the feedback and development sessions. Firstly, the focus is on the feedback about the relevancy, easiness of use and simplicity of the steps of the constructions which are reviewed in the results chapter. Secondly, the focus is set on the opinions about the relevancy of the theoretical proposals generated by the literature review behind the constructions as well as about the theoretical additions mentioned in the literature review that were not tested in the testing of the constructions and could, thus, be added later to the constructions. These are covered in the last two subchapters of theoretical contribution.

The way of the theoretical contribution reached in the step 7 of the thesis project is mostly related to the theory refinement and theory illustrations: Proposals from the theory about the applicability of the different aspects to analyse in supply chain risks as well the functionality of different tool concepts of the SCRM literature not to forget the linkage of TCO and SCRM are possibly refined based on the feedback about the functionality of the constructions and different assumptions behind them. Furthermore, by testing the different assumptions in the practical supply chain cases of the Client company, possibility for the illustration of different implications of decisions made and concepts included in the formulation of constructions in the actual SCRM process can be examined. Contribution on new theory and theory testing are less significant: new theory can practically only be contributed to the interface of the TCO and SCRM by being the only theoretical assumption with wide research gap and the lack of evidence to actually test the truthfulness of the universal theories behind the constructions might be considered limited due to low number of cases and lack of different company contexts. In addition, as noted on the theoretical evaluation of constructions, the validity of the internal logic of theoretical models proposed by different authors can hardly be challenged in this thesis as the models are not precisely replicated to the constructions.

5.3 Research quality

The quality of the research conducted is evaluated based on the following guidelines from CRA research. Firstly, the quality of the research is evaluated against the conditions suggested by Kasanen et al. (1993, 261) for evaluating the 'scientific merits' of CRA research. They propose that the CRA study could be evaluated against three levels of criteria: against general features of science mainly concerning issues of reliability, against characteristics usually connected to applied sciences mainly concerning issues of validity and finally against tradition of research field mainly concerning issues of generalizability which in their study was connected to accounting research. Lukka (2000, 10) also that especially handling of the issues of validity and reliability is an important evaluation criteria for the quality of CRA studies.

Firstly, as for general characteristics of science, Kasanen et al. (1993, 258, 261) propose that if the possibility to check the steps of the constructions and the study is conducted in a way that is objective, critical, progressive, and autonomous, the ability to repeat the study and produce similar results should be satisfied. This seems to be close to the concept of *reliability* in research (see Eriksson & Kovalainen 2008). Kasanen et al. add that this target can be met in CRA study in a successful way by producing constructions that solve problem in a real-world setting, the usability, and the connections to theory as well as wider implications are considered. Lukka (2000, 10) further proposes that especially the research process and the role of the researcher should be reported profoundly in CRA studies with sufficient level of quality and the design of research should be 'clear and fruitful' but also allowing innovativeness and emerging nature. In this study, the CRA research process followed in reporting provides the backbone for handling the issues of reliability: The careful and wide examination of research process in the methodology chapter considering the role of researcher in different steps as well as the constructions both before and after the empirical testing in chapters of literature review and results is provided which contributes to the openness and clarity of the process and possible repetition of the study. Objectiveness of the study is ensured by moving the focus from empirical work to wider implications as per the CRA process and taking a critical view into the results in the chapters of results and discussion. The criticalness and the analysis of counterarguments for the construction is mentioned by Lukka (2000, 12–13) as ways to handle the risks with lack of objectivity and the empty 'praising of results' in the CRA studies. In addition, the issues of progressiveness and criticalness are handled quite naturally in CRA study as noted by Kasanen et al. (1993) as the testing of the constructions show whether they work or not.

However, by pondering the results critically and providing implications for both wider managerial and research audience are strengthening this connection. Most significant limitations for reliability of the results are related to the high involvement of the Client company personnel in the study which adds the variable of their values and perceptions into the study which might make the repetition of the study more difficult in other contexts as proposed by Kasanen et al (1993). In addition, the autonomy of the study might be seen compromised by the history between the researcher and the Client which might also limit the objectiveness of the author. Furthermore, due to confidentiality, all the results especially related to the risks identified and analyzed in the empirical setting are not included in the thesis report which might make it harder to repeat the study. However, these limitations are tackled by aiming to take a critical view to the results in chapters of results and discussion as well as by focusing the results of the empirical study on the way of conducting the SCRM analysis and not that much on the actual risks identified.

Secondly, as for the features of the applied sciences related to *validity* of the constructions and CRA research, Kasanen et al. (1993, 258–259, 261) suggest that it should be evaluated whether the study works and solves the problem and, thus, whether the construction is relevant, simple, and easy to utilize. This is enforced by the practical origin of the research problems as well as by showing the theoretical connections. Lukka (2000) agrees and proposes relevancy of topic in both practical and theoretical dimension as well as the familiarity of the researcher with the prior academic research and generation of contribution for it as one of the criteria for the quality of CRA studies. In this study, the validity of the results is strengthened by evaluating whether the constructions work as per feedback received about the relevancy of the constructions and the theoretical proposals behind them as well about the easiness of use and simplicity of them. Furthermore, the validity is increased by reflecting the results back to theory in the chapters of discussion. In addition, the research problem was composed together with multiple employees of Client company to establish the practical starting point for relevance of the study. Similarly, profound review of literature was conducted to bind both the problem and the constructions tightly to prior theory.

However, criticism for establishing validity and knowledge contribution as per the relevance and utility of the construction has been challenged by some authors: utility and adoption are not equal to the excellent quality of the constructions if, for example, the construction is only sub-optimal or is neglected soon after implementation or other changes in relevance happen (Piirainen & Gonzales 2013; Rautiainen et al. 2017, 19, 23, 26–27). This might create limitation for the validity of this study as well as the actual utilization of the constructions in addition to the cases of the empirical study cannot be followed up due to short length of the study and large extent of the assumptions about the quality of the constructions are based on the evaluation of its potential by participants of the testing. Labro and Tuomela (2003, 424) also note that length of the research process tends to increase the internal validity of the CRA study. Furthermore, by basing the evaluation mostly on the feedback might decrease the validity but the testing in multiple supply chains in cross-functional setting increases it (see Labro & Tuomela 2003, 424; Rautiainen et al. 2017, 26–27). Furthermore, the length of the project did not allow including the entire SCRM process with steps of risk mitigation and monitoring to the constructions and to the testing. This might set a limitation to the validity of the study as the implications of the constructions to wider SCRM process and its success were not able to be evaluated.

In addition, the promotion of interests in the interviews as well as the observer bias of the researcher might decrease both validity and reliability of the results (Labro & Tuomela 2003, 424). In this study, limitation might be created as the interviews were concerning one case which represents a failure for the SCM as well as two cases with changes in the operating model – both which might create a risk of promoting own interest of the interviewed persons by, for example, being over-optimistic about the risks and their impacts. In addition, the history of the researcher with the Client might increase the risk of observer bias by the author. However, the focus being on problem solving related to the ways of the SCRM and not that much on the actual identified risks in the thesis, both types of limitations might be moderated (see Labro & Tuomela 2003, 424).

Thirdly, the issue of *generalizability* via the traditional view of the field, is reviewed by Kasanen et al. (1993, 259–261). The focus of their paper is on the accounting research, but some principles are now extended to SCM research as business-oriented field of management studies. They note that as the generalization of the CRA study is not similar to, for example, a quantitative statistical analysis with large samples, the generalization to other similar organizations might be made according to the fact that the construction works in one organization. Furthermore, the review of wider managerial and theoretical implications might reveal more general features that might be generalized to some extent. In this study, the generalization of the results is especially reviewed related to the applicability of the results to other contexts in the first chapter of discussion section. The generalizability is largely based on the potential and working of the constructions perceived by the participants. In addition, the wider implications of the study are reviewed in the second chapter of the discussion as well as by reviewing the managerial contribution and theoretical implications of the study. The contexts of the semiconductor and automotive industry of the Client company might create a context in which generalizability might be more credible but also a limitation of generalization outside the context of the companies in the sector. In addition, the company being a non-listed company with over 1000 workers in Finland and owned by a global corporation, the generalization to other organizations with different size and ownership structure might be questioned.

Furthermore, as the reporting selections due to confidentiality limited the reliability, similar limitations can be identified related to the generalizability. Rautiainen et al. (2017, 27) note a conflict of interest between the generalization of results via publication for wider benefits in the academic setting and the will of the target organization to protect the competitive advantage and business secrets. Kasanen et al. (1993, 252) proposed a similar viewpoint related to the scarcity of CRA studies by proposing that the functioning constructions might have value in financial terms and, thus, their publication to wider audience might be delayed or even blocked by the target organization. In this, thesis the limitation is made as the generalization of the actual results of risk analysis process in terms of individual risks and their impact cannot be published and generalized in most parts to protect the confidential information of the Client. However, by focusing the reporting on the way of utilizing constructions and the feedback received by the participants of the testing, the amount of confidential information is low and, thus, does not create a significant limitation. The assignment contract and the NDA was signed between the author and the target organization during the start of the project as well which is one the methods to handle the risks with delicate information according to Lukka (2000, 12–13).

Furthermore related to the generalizability, Lukka mentions issue of publishing of CRA studies which originates from the unestablished status of CRA research in general academic community. However, the CRA seem to have established role in master's thesis literature in Finland as approach was applied in wide number of the theses already in the 1990s (see Kasanen et al. 1993, 244). Thus, such issues are not expected to be related to the publication of this master's thesis. Nevertheless, as means of tackling these issues proposed by Lukka (2000, 12–13), the justification for the usage of CRA is provided in the methodology section and the theoretical contribution of the research is provided in the chapter of discussion and conclusion.

5.4 Ethical considerations

The ethical considerations of the thesis are discussed in this chapter including issues of data management, personal data, and consent. The author has familiarized himself with the responsible conduct of research of the Finnish National Board of Research Integrity and the thesis observes it (see TENK 2012).

The data management plan determining data collection, research permits as well as storing of data was composed before the data collection efforts began and it was communicated to both Client company and University of Turku. The anonymity of the participating organizations, other associated organizations and the participating employees was ensured. There is no confidential information included in the thesis and the Client company representative reviewed the thesis before submitting.

Despite the initial data management plan, certain personal data was decided to be collected. The information about the role of the interviewed persons related to Case 1 was collected but the consent to utilize this data in the public thesis report if needed was granted by the participants. This information was, however, not used in the reporting of the data in this thesis. In addition, in the construction testing, some names of the participants were collected to Excel files, but these were only used to smoothen the working in the sessions, not for analysis of results, and the cells containing names were deleted from the archived files.

The written consent to collect data was granted by the Client company in the form of the assignment contract. In addition, non-disclosure agreement (NDA) was signed between author and the Client company. As another change from the original data management plan, the written consent of the individual employees of the Client company for the participation in the data collection sessions or email threads was not directly inquired, and the decision about the participants was made by the employer of the participants. Thus, the participation of the individual employees might not be considered entirely voluntary (see Plankey-Videla 2012, 5). However, the invitations to sessions or the data inquiries via email were provided as a request by the author, which enabled the participants to refuse participating. In addition, every participant was informed about the data collection in the sessions and in the email conversations.

6 RESULTS

In this chapter, the results of the thesis are reviewed by focusing on the content of the final construction, *supply chain risk analysis tool,* to enable the understanding of the structure and the way to utilize the construction. In addition, the insight and feedback from the three supply chain cases of the Client company which functioned as the basis for development of the construction are reviewed with the related step of the construction to provide visibility to the development and to the reasons behind design decisions.

The chapter is divided into five subchapters based on the steps of the final construction illustrated in Figure 8. Each subchapter is reviewing the step description of the final construction as well as overview, insight, and feedback from the testing of the step in cases 2 and 3 not to forget the possible insight from the Case 1 relevant to the step development. Detailed SC risk and risk impact cost content of the cases is not reviewed in depth due to confidentiality reasons. However, certain risk examples from the cases are utilized together with the related step of the final construction to demonstrate the utilization of the tool and the way of working.

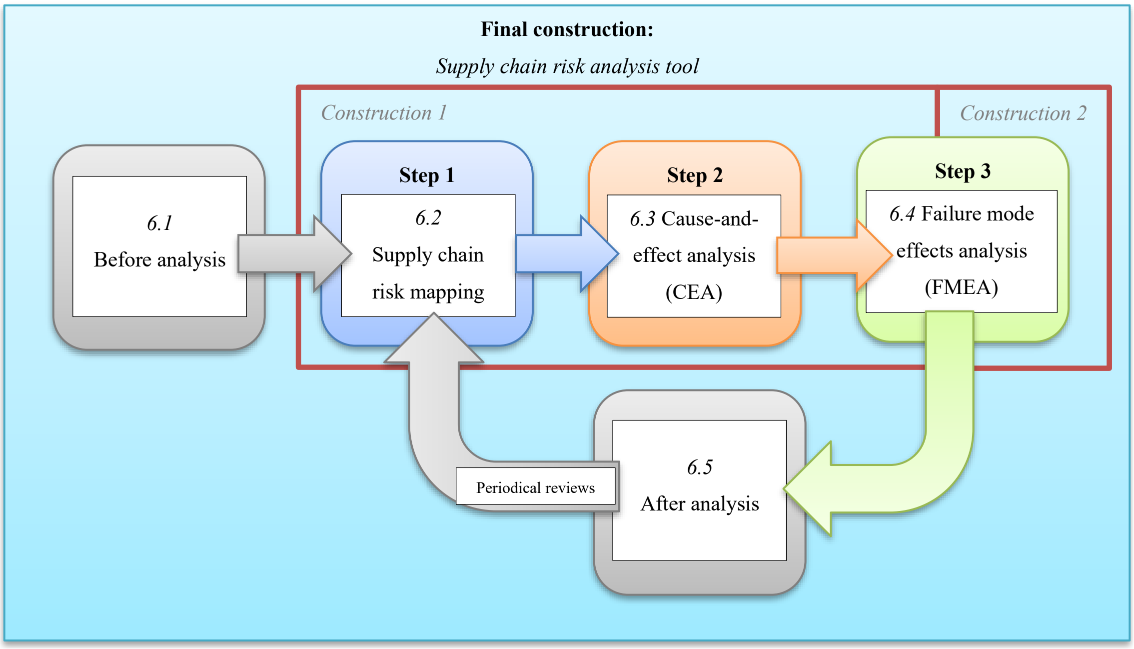

Figure 8. Steps of final construction and related subchapters.

In addition to step-specific development of the way of working, the analysis tool saw a more general change of structure in the process. The 3-step process of construction 1 focusing on risk impact identification and the 4-step process of construction 2 focusing on the total cost of risk analysis were combined into one construction of supply chain risk analysis tool. This tool and way-of-working includes preparation step called 'Before analysis', step 1 of supply chain risk mapping and step 2 of cause-and-effect analysis (CEA) similarly as the construction 1, step 3 of failure mode effects analysis (FMEA) including both the FMEA step of construction 1 and the total cost of risk work of construction 2, and the aftermath working step of 'After analysis'. The after-analysis step is linked back to step 1 through periodical reviews and updates of the analysis.

The reason to combine the two constructions into one originated from the will to create one systematic working tool for the Client instead of two which was considered clearer approach for the users of the tool by the author. In addition, the FMEA working of construction 1 and the total cost of risk working of construction 2 were already forming a consequent step of supply chain risk analysis, happening mostly in the same FMEA framework, and tightly linked to each other by identified risk impacts and their evaluations. Thus, the change is more cosmetic than changing the actual logic of analysis.

6.1 Before analysis step

Based on the testing round of the construction, the proposal of the TCO literature to add training material to the analysis tools was found potentially beneficial by the participants of the feedback session. Thus, comprehensive instructions for the utilization of the supply chain risk analysis tool were prepared by the author. In addition to step-to-step instructions of the process, more detailed version of process flow diagram of Figure 8 was provided to improve the understanding of the overall picture about the entire process. This was inspired by the feedback that 'big picture' in the process and the significance of the specific steps in the process was sometimes felt to be lost by the participants.

To ensure the proper basis for the analysis, the guidelines for the preparational activities of the analysis were included in the instructions. These activities were set to include selection of supply chain to analyse, selection of analysis team and facilitator for working, creating a general schedule plan, creating a shared working MS Excel file for the team, and organizing a kick-off and development meeting for the process. These six activities and the feedback from the testing behind them are presented next.

Firstly, the *selection of the supply chain* to analyse was instructed. Following the logic of the tested supply chain cases as well as the need to address unknown properties included in change, it was proposed that new supply chains and supply chains facing significant changes including changes in life cycle phase could form a good basis for targeted supply chains. The applicability of the tool in different life cycles and overall life cycle thinking was encouraged by the received feedback. In addition, according to the feedback, it was encouraged to conduct the analysis early in the projects with supply chain impacts. However, utilizing the results of the analysis might still be difficult in the very early stages of the planning with lots of uncertainties in supply chain design as was communicated by the testing team of case 2. Furthermore, as noted by the TCO literature, the analyzed object should be significant to justify the heavy analysis process. The analysis process was found rather heavy in terms of amount of work needed at least for less significant supply chains. Thus, rule of thumb was proposed that the analyzed supply chain should have at least 10 percent contribution to next two years of sales plan and have at least one highest priority supplier included based on the Client company's classification of suppliers. Later, the first criterion was found problematic especially from the perspective of supply chains with products on development phase as they would not possibly create sales in near time window. Thus, the first criterion was changed to encourage selection of supply chain that contribute 'significantly' to sales of the Client company.

Secondly, *the selection of a team* to analyse the supply chain was instructed. Following the roster of the testing teams of cases 2 and 3 found mostly suitable as per the feedback, it was noted that cross-functional team composition including at least experts of sourcing, outsourcing, supplier quality, logistics, sales, and information technology. The participation of sales expert was added to the instructions based on the feedback from testing highlighting the issues with lacking presence of sales expertise in the process especially when considering the impacts of the risk to sales which was the case in the testing. Even though highlighting the need for cross-functionality, the feedback also included warnings not to increase the team into parties with no relevant insight into analysis. In addition, usage of the cross-functional teams focusing on planning, validation or operating the analyzed supply chain as a basis for team composition and consideration of including research and development personnel especially in early life cycles was encouraged as well in the instructions. Despite the proposal of the literature, the possible participation of external parties of customer and supplier in the analysis was found problematic by the testing team due to confidentiality issues. However, the data gathering from supplier based on communication forums and audits as well as escalation of risk issues to partners if necessary was found beneficial and encouraged in the instructions.

Thirdly, it was instructed to *select a facilitator* for the working to host the working sessions and prepare the materials for the analysis team in the process. This was found beneficial by the author on the testing as the group working in sessions could be utilized for the actual analysis instead of preparation and manual working. The experience on the SCRM, available time resources for facilitating and the organizational responsibilities of risk management were instructed to be guiding factors for the selection. It was noted, that SCRM responsibilities were not clearly defined in the organization structure of the Client so more general 'risk management responsibilities' was selected for guidance.

Fourthly, instructions for *a general schedule plan* were provided. Planning of an analysis process before in terms of schedule was considered a good practice by the author and a way to plan the resource allocation from the participants for the process. As a rule of thumb based on the testing of the constructions in cases 1 and 2, the total time taken by the analysis was estimated to around ten weeks with following share of steps: two weeks for preparation and creation of supply chain flow diagram, two weeks for risk mapping, two weeks for CEA and four weeks for FMEA work including total cost of risk assessment.

Fifthly, the creation of *shared MS Excel working file* for the analysis team was instructed. Based on the testing of the constructions, a blank Excel file with sheets for instructions, steps and supporting classifications as well as calculations was created to be utilized in future applications of the tool. The blank file to be copied for analysis team was stored into document archiving application of the Client to enable access by relevant personnel. Even though occasional feedback about 'getting lost' in the details of the file was reported, the file with sharing via, for example, MS Teams functionalities proved to be able to carry through the analysis. Multiple improvements in visualizations – for example font sizes criticized on the feedback – were done to improve usability of the file. Even though Excel file was selected as a primary tool, especially the development of FMEA tool to Client company's existing FMEA application environment was studied but the development was considered too heavy for the time frame of the thesis project by the author. The potential of linking of the cost calculations to other Client systems was inquired from the analysis team but it was considered to deliver low benefits due to tight IT resources and the lack of data utilizable in analysis from the systems.

Finally, a *30-minute kick-off and scoping meeting* was instructed to be organized. Kick-off meeting was conducted in the case 2 as a separate session but included in the first analysis session on the case 3 due to schedule issues. This meeting was not included in the original instructions as a stand-alone activity, but it was considered a good addition by the Client company in the review of changes done to the tool based on feedback. The need was especially triggered by a viewpoint by some of the personnel that certain risks identified in the testing were on some extent out of SCR scope, already managed by other business processes and not specific enough for the analyzed supply chain.

As a remedy, the tiers of the supply chain and the general types of risk excluded in the scope of the analysis were instructed to be aligned in this kick-off session. As a rule of thumb, parties from suppliers' suppliers to customers on the supply chain and supply chain risks originating from the SC partners and material, information and financial flows of the chain were as least advised to be included. However, internal product quality risks as well as research and development project and product risks were considered out of scope as they were covered by other processes. Furthermore, focusing on the risks originating from SC specific design decisions – for example, political risks in specific country – and not on risks generic to entire Client business – for example, market changes in entire portfolio – was strongly recommended.

Despite this will to find more focused boundaries for analysis to reveal as relevant information as possible, the feedback based on working was other ways supporting the holistic approach of analysis including wide set of risks and cost components as it was considered to support depth of analysis vital on delivering additional value by analysis. In addition, the later narrowing down of risks was considered to support holistic approach and was included in later steps of the process. Thus, the viewpoints about the right level of comprehensiveness to enable depth of analysis versus the tighter scope to enable relevance were slightly divided.

6.2 Step 1: Supply chain risk mapping

The preparatory phase in the final construction is followed by the first actual analysis step, *supply chain risk mapping*. As was the case with the theoretically based construction 1, the step 1 is including two main activities: creation of supply chain flow diagram or map divided into separate 'step 0' in the instructions of the tool and actual supply chain risk mapping focusing on identifying risk sources from the chain.

In the testing of the step 1, supply chain flow diagrams were drawn for both cases 1 and 2 former including 9 supply chain parties from tier 3 to customers of the client and around 20 flows between the parties and the latter including 20 parties from tier 4 to customers of the client and 34 flows between the parties. The greater number of identified components of the supply chain is probably implicating the greater complexity and better knowledge of the already established supply chain of case 3. In addition, it might also be impacted by the fact that the flow diagram of case 2 was drawn more co-operatively and for other SC planning usage whereas diagram of case 3 was mostly drawn by the author with good knowledge of the chain. However, in the actual supply chain risk mapping activity, 51 risk sources were identified from the case 2 and 40 from case 3.

As general feedback about relevancy of results of step 1 based on testing, the analysis was found to improve clarity and broaden view about the big picture of the supply chain as well as being comprehensive way of working and potential for standard tool for analysis. However, the step 1 was found to provide mostly quite standard and already known insight especially in the already well-known supply chain of case 3. In addition, the scope was considered big and complex, easily focusing on dramatic rather than more ordinary risks and suitable level of thinking was found hard to recognize. As for the simplicity and easiness of use of the tool, the step was found rather easy to conduct, systematic and clear. However, the viewpoints about the time usage and working style in remote were mixed: Some considered the step requiring lots of effort, time limiting detailed analysis and remote working being difficult. Others found the step to save time in the long run and collaborating in remote MS Teams environment working well. Furthermore, the analysis of risks starting from the risk sources seemed logical for the participants.

In the next sections, the process, instructions, and feedback for the first activity of the step 1, drawing of SC flow diagram, are reviewed. After that, the actual supply chain risk mapping and the supporting supply chain risk source classification are addressed.

Drawing of the supply chain flow diagram

In the testing of the cases 2 and 3, the drawing of supply chain flow diagram and the utilization in risk analysis received positive feedback. Map was considered good for understanding the flow and it was commented that usage of flow diagrams should be used in other similar occasions as well. A simple example of SC flow diagram can be found from the literature review (see Figure 4).

To improve the understanding of the significance of the flow diagram, the aim of the activity was stated on the instructions as follows: '*To draw a holistic map / flow diagram of supply chain to help identifying risks from supply chain*.' As for the actual working, two alternative paths were provided: usage of existing diagram or drawing a new one.

If adequate SC map already exists, instructions state that in can be utilized without drawing a new map. However, at least all the parties of the chain inside determined scope, flows of material, information and finance, material ownership in different tiers of the chain and swimlanes separating different tiers of the chain were required be included to continue with existing map. As per feedback received, the diagram should also include the suppliers for packing of materials which can in some instances be forgotten from the usual SC structure.

If no map meeting the criteria above is available, one should be drawn. Room is left for different ways of conducting this activity. It is stated that the drawing can be assigned to one person and the results cross-checked in analysis team in a session of 30 to 60 minutes if the person has sufficient knowledge of the chain. This is reflecting the way of working applied in the more familiar supply chain of case 3. If this is not possible due to unknown components of the chain especially in planning phase, the diagram should be drawn together in a longer workshop session reflecting the working style with the planned SC design of case 2. For both ways of working, physical working is preferred according to the reported difficulties of working in a remote mode. As for technical solution, MS Visio environment is a good example of suitable applications for this activity. In addition, the usage of the flow diagram in other supply chain planning and communication activities is encouraged. This is based on the working in case 2 where the flow diagram was composed for the larger SC planning usage than only the risk analysis.

Based on the maps drawn for the cases, following additional components are also proposed to be added to the drawn map. Firstly, illustrating the process steps of manufacturing especially when dealing with outsourced production can provide additional insight into SC structure. Secondly, the inter-company flows can be highlighted with, for example, thicker arrow to separate them from internal logistics. The proposal of the literature to highlight international flows was found irrelevant as in the international chains of the Client, most of the inter-company flows were crossing borders. Thirdly, the applied handling unit and IP ownership in the tiers of the chain was found beneficial to illustrate. In the chains of the Client in semiconductor industry, the IP ownership might have large differences between, for example, chains with and without outsourced production and sometimes IP is jointly owned with customers or suppliers. Furthermore, the handling unit of the products might change between, for example, raw materials, wafers, components, and reels which has implications especially on material handling and information management. Finally, on the diagram of the case 2, the analysis team highlighted components and features of the chain that were unknown to take into account the uncertainties on the SC design. This can be the case if, for example, supplier selection processes are not finished. This was also supported by feedback stating that the weakness of the flow diagrams lies on the fact that they can only show what is currently known.

Supply chain risk mapping

After the SC flow diagram has been prepared by the team, the analysis can move towards brainstorming the potential risk sources for risk scenarios from the analyzed supply chain. The aim of the activity was stated as follows to increase the understanding how the step fits into the bigger picture: '*To establish list of risk sources (e.g. supplier financial trouble or market changes of raw materials) that might trigger risk events (e.g. supplier shutdown or availability issue) in SC.*'

First sub-activity of the risk mapping is the *preparation material* provided by the facilitator to the team to assist smooth working on the actual brainstorming. The logic is that less intervention and time spent on clarifications is needed by facilitator which was found problematic as per the feedback. Preparation material is instructed to include short description of the way of working in the session as well as the risk source classification table and prepared SC flow diagram for familiarization with the key background sources of information for the working. The aligned scope of the analysis and the aspiration to identify risks that are specific to the SC design are instructed to be reminded in the preparation material to maintain the relevancy of the results. Furthermore, risk mapping of similar supply chain analysis can be attached to the preparation material for benchmark based on feedback proposing usage of benchmarking of other projects in analysis. This instruction is given to other steps of analysis as well. Finally, the possibility to mark risk sources beforehand to shared Excel file is instructed to be given to enable different styles of working of the analysis team.

As a second sub-activity, the actual identification of supply chain risk sources is done in a form of *brainstorming sessions* which proved to deliver mostly utilizable list of risk sources on the testing. Apart from the one or two brainstorming sessions focusing on all risk sourced utilized in the testing, three sessions of 45 minutes each focusing on one flow of material, information and finance utilized in the risk source classification of appendix 1 are instructed. This more focused way of working per session was directly proposed in the feedback received and it also helps on identified issue of unnecessary usage of expert time when including entire analysis team to entire brainstorming as people can be included to sessions as per their expertise. In addition, this change is expected to bring more focus to the working called for in the feedback and adding more time for working as per theme possibly enabling more detail in working in terms of, for example, operations of suppliers requested in feedback. For the sessions, remote working was utilized in the testing. However, due to difficulty of brainstorming in remote mode, physical working with usage of post-it notes on flip boards, is proposed as a preferred way of working.

The workflow of the session is instructed as follows: First ten minutes is used for running through the way of working for making sure that everybody is on the same page. Then, the next 20 minutes are used for individual brainstorming of risk sources related to the theme of the session with post-it notes on physical mode and on shared MS Excel sheet with special area for all the participants to brainstorm their ideas. The SC flow diagram and the SC risk source classification of appendix 1 are used as sources for brainstorming. Finally, the last 15 minutes are used for run-through of identified risk sources first focusing on the location-specific ones by running through the SC flow diagram and then the general ones. This way of run-through was utilized in the testing as well. However, it caused issues if the locations were not stated with the sources.

In addition to the actual risk sources, the location of the source if it is originating from specific location in SC, type of source in classification to enable classification of identified sources and concerned life cycle phases if the source is related to certain phases are instructed to be stated with the risk source. The location was found irrelevant in this phase of working by some of the participants but later it was found relevant in the cost calculations and interpretation of findings. Due to this mixed feedback, the location was removed as a separate column of data from SC risk mapping but asked to include in the risk source description if found relevant. The life cycle phases included in this analysis step was as well proposed in the feedback even though their involvement was minor on the testing phase. Furthermore, the consideration of controllability of risk sources was removed from the risk mapping as it was not found relevant on this phase of working. However, the relevancy was noted to be higher when actual risk scenario specific actions are considered based on the results of the analysis. The removal of location and controllability as separate columns of data was done to improve the clarity of the Excel tool criticized in the feedback. In addition, the aligned scope and SC specificity are instructed to be reminded and the clarity of the risk source statements on the brainstorming is to be ensured based on feedback about issues with interpreting some of the risks identified.

Thirdly, after the three brainstorming sessions, *the enhancement and summarizing of results* is conducted by the facilitator. According to the feedback, more time should have been used for enhancing the results and summarizing them for easier communication and usability. In this step, the activity is, however, instructed to be done by facilitator to limit the burden for the analysis team. As per the feedback, summaries and enhancement are included in the other steps of working as well. This activity is also a potential remedy for issues communicated in feedback with using Excel tables as output and documentation of results and unclarities of the Excel in brainstorming.

As a first step of summarizing, the summarizing of results is instructed to be done to risk classification of appendix 1 as per risk source types for easy handling of the results. The enhancement of results is done by filtering out risk sources that do not fit to the aligned scope of working, combining overlapping risk sources, and dividing risk sources if different options seem relevant. Latter can be the case with, for example, dividing error in forecast planning to too high and too low forecast. Secondly, after enhancement of the results, the summary to, for example, MS PowerPoint slides is proposed based on the noted limitations of the Excel file. In the final summary, the effort should be made to visualize the results by, for example, placing the location specific sources on the SC flow diagram. Usage of visualizations and diagrams was proposed in the feedback as well.

The risk source classification based on the categorization of supply chain risk types from automotive industry by Blackhurst et al. (2008, 149) was found useful by the participants of the testing. The classification used as a source of information for brainstorming of supply chain risks and developed as per it can be found on the appendix 1. The classification saw bunch of changes during the process to find the fit with the context of the Client. This kind of tailoring is encouraged by Blackhurst et al. as well.

Firstly, based on the literature review, the types or categories of risk sources were divided inside the three flows of the supply chain. Secondly, the risks of Blackhurst et al. that seemed to resonate best with the supply chain context of the client were added to the table as risk source examples marked on normal black on the appendix 1. Thirdly, based on the eight risk sources that led to the supplier shutdown in the case 1 according to the interviews, risk examples marked on bold blue on appendix 1 were added to the classification. Finally, during and after the testing of the tool on cases 2 and 3, more risk examples, and new risk type of manufacturing which are marked on bold black on appendix 1 were added to the classification. In addition, the risk type of dependency marked on bold red on appendix 1 was deleted due to overlap with the risk sources of ‘supplier commercial'. Furthermore, as the flexibility to add more items to the classification was found important for the usefulness of the classification, 'other' categories were added to all flows in the classification as can be seen on the appendix 1.

Certain critique towards the classification was related to the fact that cost-related items are spread into multiple different types of risks including capacity, quality, and commercial items. However, the correction to combine all the cost-related risk sources inside single risk type was not found convenient by author as it would have broken the logic of classification which divides all the risk sources inside their related flow and type and, thus, no action was taken.

In addition to around 55 coded feedback items included in the development of step 1, few triggered no action on the development. Firstly, the proposal to consider risks causing positive outcomes for the SC was excluded due to definitions of SC risks by the literature highlighting the negative outcomes. In addition, feedback items of including analysis of occurrence, severity, and detection, and considering significance and likelihood of different risk sources and categories was not included in the development as they were concerning later steps in the process. However, avoiding analysis of likelihood was a key assumption in the proposed construction and, thus, this feedback can be seen as an interesting piece of critique.

6.3 Step 2: Cause-and-effect analysis (CEA)

After the potential risk sources in the analyzed supply chain are identified, enhanced, and summarized, they are linked to the consequent risk events and risk impacts of these events as well as risk drivers impacting the likelihood that risk event is triggered and severity of the impacts. The step aiming to identification of these risk scenarios, cause-and-effect analysis (CEA), is including three activities: preparation of table and material, workshop session of 120 minutes and summarizing.

Based on the first testing round and similarly as with the step 1, the tool was found to deliver 'broad and detailed' view to risks with systematic way of working and good team engagement. Furthermore, the logic of linking the risk sources with other risk components to form risk scenarios was found logical. However, again, the insight was not found extremely relevant by being quite standard and by lacking novel findings. In addition, the follow-up of the results, remote working and comprehension of risk scenarios was found difficult. As an outcome 29 risk scenarios were identified in the testing of case 2 whereas 20 risk scenarios were identified from case 3.

As for the first step of working, *the facilitator prepares the working table* of the shared Excel file by adding a suitable summary of identified risk sources to the table to assist on working. After that, similarly as in step 1, the preparation info is provided for the analysis team including the identified risk source summary, classifications of risk impacts and risk drivers as well as benchmark of analysis about similar supply chain. Making notes to working table beforehand is again allowed. In addition, the clarifying questions about identified risk sources as well as the classifications are encouraged beforehand to smoothen the working in actual session. To increase the novelty and relevancy of results highlighted in the feedback, the targeted case specificity of the risk scenarios and the aligned scope of the working are reminded in the preparation material.

As a second step, the actual CEA working happens in *one 120-minute workshop session* with the entire analysis team working in pairs. In a testing phase, the working with narrower team of experts was tested in case 3 whereas the entire analysis team working as pairs participated in case 2. The latter was found to enable smoother working and it also generated larger list of scenarios. Thus, working with entire analysis team was selected for the final construction by author and it was expected to partially tackle the issue of remote working in this step highlighted in the feedback.

Table 10. Cause-and-effect analysis table & risk scenario example.

#	**Risk source / Source of failure** *(e.g. supplier profitability)* 1 or more per scenario	**Risk event / Failure mode** *(e.g. supplier shutdown)* Only 1 per scenario	**Risk impact / Impact of failure** *(e.g. buffer building, delays)* 1 or more per scenario	**Risk drivers** *(e.g. risk culture, visibility)* 1 or more per scenario	**Comment** *(e.g. location, only validation phase)*
	"Due to sources 1 & 2..."	*"...event 1 happens..."*	*"...and causes impacts 1, 2 & 3..."*	*"...driven by drivers 1 & 2."*	
X	Poor support from supplier in capacity allocation, Capacity shortage caused by general customer demand, Long lead time	Material availability not on requested level	Customer delivery delays, reputation issues	Low negotiation power with suppliers	Supplier Y, all life cycles

Furthermore, physical working with three flip boards, one for each of the flows of supply chain, divided for the columns of sources, events, impacts and scenarios in which the risk scenario can be visualized with post-it notes was proposed as a preferred way of working instead of remote working as a respond to the difficulty of remote working pointed in the feedback. In addition, the more visualized physical working with post-it notes is expected to ease up the modelling of dependencies between multiple causes and multiple impacts in the scenarios that was found difficult as per the feedback. The working table structure that can be used in both physical and remote working is shown in table 10. One example of identified risk scenario in the testing is marked to the table and another general example based on the case 1 is seen on the header.

The workshop session is divided into three phases: First 15 minutes is used for going through the way of working, possible clarifications based on the preparation material and dividing the analysis team into pairs. Pairs can be drawn but also pairing based on synergies of functions by, for example, making sourcing and supplier quality work together was found beneficial. The pair working was found to function well as per the feedback. However, feedback also highlighted that the pairs should decide the simple practical matters like writing responsibilities to enable smooth working.

The second 45 minutes is used for rolling brainstorming where each pair spends 15 minutes focusing on supply chain risk scenarios of one of the three flows supply chain. The scenarios should emerge from sources identified in the first step. The supply risk impact classification of appendix 2 and supply chain risk driver classification of appendix 3 function as a background material but more can be added if suitable ones are not found. As is noted in table 10, one risk scenario should include only one risk event based on the logic of FMEA where failure mode works as the unit of analysis. However, multiple risk sources, drivers and impacts can be included in single scenario to reveal the interconnectedness of the factors. In addition, participants should be reminded of the scope and supply chain specificness of the scenarios before working is started. The structure of five themes in the actual working presented in theoretically based construction 1 was abandoned on the final construction by the author already before the testing to enable more freedom on how the scenarios are brainstormed and to reduce the time used for facilitating. However, due to this change the causality of the risk sources is possibly not reached with similar kind of depth.

The final 60 minutes is reserved for going through the brainstormed scenarios and enhancing the results. According to the feedback, the risks were found sometimes difficult to understand without mutual discussion and more time was needed for working so an hour was decided to be used for this activity. After reaching mutual understanding of the identified scenarios, duplicate scenarios should be combined, the wording of scenarios should be made so clear that they can be understood by personnel outside the team and scenarios outside the aligned scope should be removed. Furthermore, the splitting of scenarios should be considered if relevant differences occur between different life cycle phases and supply chain locations and tiers. Consideration of life cycle phases was found beneficial theoretically based addition to the working in the feedback and the splitting of scenarios was found important for the cost calculations and interpretation of the results of the entire analysis. Finally, the risk scenarios should be numbered as can be seen on the column '#' of the table 10 to give unique attribute for the scenarios.

After the workshop session, the facilitator should *summarize and visualize* the identified scenarios into MS PowerPoint file. According to the feedback, the summarizing and visualization of results was found beneficial development action. In addition, the MS Excel sheet was not found adequate for this kind of activity and the results as well as the interconnectedness of different sources leading to one event and multiple impacts originating from it were difficult to follow from table form. Example of suitable visualization of risk scenarios is flow diagram, which was already mentioned as one way of visualization in literature review. The example risk scenario of table 10 is illustrated in the flow diagram of figure 9.

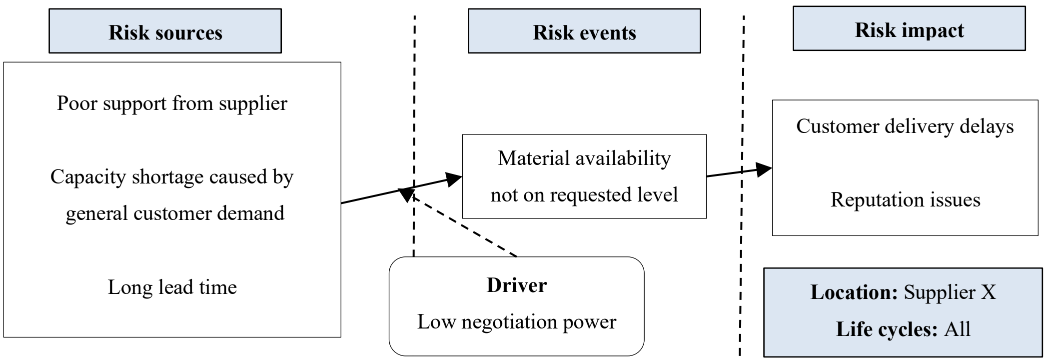

Figure 9. Risk scenario example on flow diagram.

As for the *classifications supporting the working*, the supply chain risk impact classification of appendix 2 and supply chain risk driver classification of appendix 3 were created based on the literature review. In addition, the classifications were modified based on the cost analysis of case 1 and testing of the construction in cases 2 and 3. Such changes originating from case 1 are marked on bold blue and changes originating from cases 2 and 3 are marked on bold black.

The supply chain risk impact classification of appendix 2 was found useful in the feedback of testing. It was first created for the analysis of case 1 to support the identification of different supply chain risk impact caused by the analyzed supplier shutdown. The nine types of supply chain risk impacts based on literature review were grouped into financial impact, process performance impact and resource-related impact and financial impact was further divided into sales and costs as has been presented by the literature. In addition, different examples of these nine types of risk impact were added to the table. Around 60 different items of impact were identified in case 1 and additional examples marked on bold blue were added to the classification. After the testing in cases 2 and 3, additional examples marked on bold black were added to classification. In addition, the sub type of 'time' was changed to 'delay' as per discussion with the academic supervisor of the thesis and the examples were modified accordingly. Furthermore, flexibility to add more items to the risk impact classification was emphasized in the feedback of the testing. Thus, the 'other' classes for emerging risk impact classes were added to the finalized risk impact classification.

The supply chain risk driver classification of appendix 3 was found to bring more content to analysis according to the feedback of testing. Similarly as with the impact classification, the classification was first created for the analysis of case 1 as per the literature review findings as separate classifications of supply chain risk drivers and risk impact drivers at the time. Based on the around 20 different risk drivers identified in the analysis, the driver types of lead time and process standard were added to classification. Later, based on the testing of the classification in cases 2 and 3, the new types of drivers highlighted with bold black were added to the classification. The increased amount of driver categories was also raised as a possible development item in the feedback. However, it was noted that identification of risk drivers was not an easy task for some of the risk scenarios. Thus, to ease up the utilization of the drivers and to simplify the analysis, the risk drivers of SC complexity, SC integration, lack of confidence, flexibility and perception of risk were combined with the risk impact driver categories of relationship and influence, SC environment and time. They were also combined in the CEA and FMEA tables of the analysis tool to create a coherent set of tools. In addition, the driver type of 'amount of buffer' was changed to 'flexibility' as the type was including more kinds of different components of flexibility rather than just inventory usually referred with the word 'buffer' at the Client company.

As was the case with step 1, in addition to around 30 feedback items, few triggered no special action. Firstly, multiple workshops with different focuses as was done on step 1 was proposed in the feedback but to limit time used for the step and to enable teamwork with the entire analysis team in the workshop, one workshop with rolling brainstorming was selected. Secondly, the modelling of dependencies between different impacts as well as consideration of different severity of impacts was found to be related to the working in the step 3 of FMEA. Finally, a single feedback item of 'structure change' was provided which caused no impact due to its lacking explanation.

6.4 Step 3: Failure mode effects analysis (FMEA)

After the risk scenarios have been identified in step 2, they will be evaluated in the failure mode effects analysis (FMEA). The aim of this activity is stated as follows in the instructions: '*To analyse & prioritize the risk scenarios identified in step 2 by (1) evaluating the frequency of how often the risk scenario might happen, (2) evaluating the current detection & control methods and how quickly the realized risk event of the scenario is identified and recovered from, and (3) prioritizing the risk scenarios based on the calculated total cost of risk impact*.'

Based on the testing of the step on the cases 2 and 3, the FMEA was found to provide relevant results for decision-making and to be lot more concrete way of working than the previous steps of analysis as commented by one of the participants. Especially, the usage of cost estimates as a basis for risk prioritization gained strong support on feedback and the FMEA was found to provide, with a systematic way, 'concrete evidence' of the actual costs related to supply chain risks that could support on creating less difficult and more informed decision-making related to supply chain risk. In addition, the FMEA framework was found suitable for utilization especially due to its ability to compare different risk scenarios to each other. However, criticism towards the way of working was related to its complicatedness, difficulty in remote setting and large amount of time resources required. In addition, the cost calculations were found hard to follow by participants. However, at least some participants found the way of working simple enough at least. In the testing, total of 23 scenarios of case 2 were analyzed, assessed, and prioritized while 6 scenarios of step 2 were excluded due to overlapping with other scenarios or for being out of scope. For case 3, 17 scenarios were analyzed and 3 excluded due to overlapping. The total costs estimated for risk scenarios ranged from around 20 million euros to less than one thousand.

As noted, the step III of theoretically based construction 1 and the construction 2 were combined to this FMEA working of step 3 of the final construction developed based on testing and feedback. However, to improve the understanding of the reader especially about how the feedback received links to the two constructions based on literature, the sub-tasks of construction 1 related to the evaluation of frequency, detection and control methods, speed of detection and business recovery time are handled next as activity 1. After that, the activities of construction 2 related to matching the risk scenarios with cost components and calculating the total cost of supply chain risk scenario are addressed as activity 2.

Activity 1: FMEA

The way of working with FMEA starts with similar preparational activities than in previous steps. After that, the risk scenarios identified in the step 2 are analyzed in the first session of the step 3.

Table 11. FMEA analysis table of activity 1 of final construction.

	Sensitivity analysis	Frequency	Detection / current control			
			Detection method	Speed of detection	Current controls	Business recovery time
Description	Best or worst case?	How frequently occurs? (times / year)	How would be detected at the moment?	How long it takes to detect the risk event? (days)	How is prevented at the moment?	How many months it takes to recover from risk event?
Input	Best-case/ Worst-case	Evaluation as per table 12	Evaluation	Evaluation as per table 12	Evaluation	Evaluation as per table 12
Scenario X	Worst-case	1	Lack of order confirmations	7	Follow up of capacity, reliable forecast	6
	Best-case	0,5		-30		3

Firstly, *facilitator prepares the tool* for the analysis by adding the risk scenarios identified in step 2 to FMEA table. The inspiration for the FMEA tool was also acquired from other FMEA tables utilized by the Client company. The table with column of analysis in activity 1 is illustrated in table 11 with the same risk scenario example than on table 10 and on figure 9. In the actual tool, there is own column for all the five items of risk scenario information of CEA. In addition, the facilitator should gather the following input data to be used on the cost calculations already on this phase: time frame of analysis, the estimated sales margin of the products supplied through the chain and, target inventory in pipeline per tier of SC. Time span of the current sales and operations planning process was used for the analysis time frame to enable visibility to sales plan but, for example, entire life cycle of products supplied by the chain can be used especially if it is already forecasted. The general revenue expectation of the Client company multiplied by the sales plan of the analysis time frame was used instead of actual sales margin calculations to simplify data gathering. The target total amount of inventory in the supply chain was estimated to be around 3 and 6 months in the two cases.

Secondly, after the tool is prepared, *preparation material i*ncluding description of the way of working, summary of risk scenarios identified in step 2, cost component list to be reviewed on activity 2 and benchmark of similar analysis is provided to the analysis team. Questions to clarify uncertain items are again encouraged but there is no need for notes beforehand on this phase as the working is more facilitator led than in the previous steps.

Thirdly, The FMEA work of activity 1 happens in the first of the two sessions of the step 3. This *first session of 90 minutes* is executed again with entire analysis team. The team working was found beneficial in the testing, and it provided better mutual understanding and view of the risks which was speculated to optimize total time used for analysis. However, it was also found as a weakness that teamwork is required to reach agreement on evaluations instead of less labor-intensive analysis done by single person. The remote meeting was once again found to be difficult and even non-feasible way of working so physical session with, for example, the analysis table projected to meeting room screen is preferred way of working if possible.

First 15 minutes of analysis is used for going through working, clarifications for preparation material and going through example of working like the one utilized in table 11. The example of way of working provided before the working starts was especially notified in the feedback of this step. In addition, careful supervision that everybody is on the same page in working was another supporting activity considered necessary.

The next 60 minutes will be used for actual analysis of the columns of 3 to 7 of table 11 for all the identified risk scenarios together with the team based on expert evaluations. As can be seen in the table 11, the scenarios will be evaluated based on best-case and worst-case alternative of the scenario. This kind of splitting of the scenarios into categories to enable sensitivity analysis instead of using average case or extreme case was proposed on multiple feedback items. In addition, as in supply chains of early life cycle phase there are multiple uncertainties in SC design, this kind of sensitivity analysis was expected to assist on taking them into account as well.

As for the actual factors of analysis, the scenarios are evaluated on three numerical measures of frequency, speed of detection and business recovery time as per the findings of literature review. The alternatives for these three measures listed on table 12 were provided to assist the evaluation work and the functioning of calculations. The alternatives were based on pure assumptions, and it is likely that in other context other alternatives can be found more adequate. The usage of the different factors of analysis was found beneficial and absolute values of time or frequency were found easier to evaluate than scales. The replacement of likelihood with frequency seemed to resonate well to the participants but certain feedback during the testing also implied will to include this more traditional factor of risk analysis in the evaluations. However, according to the discussion had with one of the senior managers in the late phase of the project, the likelihood was also considered a factor that could be added to analysis in the follow-up of scenarios if found to provide additional value.

Table 12. Alternatives for time-related measures of FMEA.

Frequency (times per year) Example: Damage in transit happens twice per year **-> 2**		**Speed of detection (days)** Example: Supplier notifies around year before end of life of component **-> -365**		**Business recovery time (months)** Example: It takes 12 months to re-establish customer deliveries **-> 12**	
52	Once per week	-730	2 years or less before incident	0,25	1 week or less
12	Once per month	-365	Around a year before incident	1	Around 1 month
4	Oncer per quarter	-180		3	
2	Twice a year	-90		6	
1	Once a year	-30		12	
0,5	Once in 2 years	-14		18	
	(added after analysis)	-7		24	
0,2	Once in 5 years	-1		36	Around 3 years
One	Max. once in a product	1		60	5 years or more
timer	life cycle	7			
		14		*Or*	
		30		Precise number	
		90			
		180		*Or*	
		365	One year after incident	Not applicable	Not possible
		730	Two years after incident		to recover
		Or			
		Precise number			

As for the evaluation of current detection and control methods, according to the feedback there was not enough time used for in-depth in analysis. However, the evaluation seemed to have been found beneficial and it should be continued later in the process. The 60 minutes of group working allocated for the analysis of the methods in addition to the time-related evaluations is expected to support more in-depth analysis than in the testing. In addition, the detection and control methods are instructed to be revisited after analysis.

For the last 15 minutes the assumptions about the inventory in the pipeline, and time span of analysis should be aligned. In addition, an extra session of half an hour should be booked in addition, if not all the analysis was able to be carried in 90 minutes.

In addition to methods and time-related evaluations, the affected party by impact and responsible party of managing the risks originally included in construction 1 were discussed for the risk scenarios in the testing after the cost calculations and prioritization of scenarios. However, this factor of analysis was not found very relevant by the feedback and, thus, it was removed from the analysis at this stage. Furthermore, the responsibilities should be considered when discussing the action plan for the risk scenarios after analysis. In addition, this removal was expected to tackle some of the complicatedness of the analysis pointed out in the feedback.

Activity 2: Total cost of supply chain risk

The working with calculations of total cost of supply chain risk of scenarios and prioritization of risks starts, firstly, with linking of cost components to risk scenarios, secondly, by calculating cost of one risk occurrence, thirdly, by calculating the total cost or risk and, fourthly, by setting of initial priority by facilitator. Fifthly, these first versions of calculations are then reviewed by analysis team in the second session of step 3 and, finally, the results are summarized by the facilitator for further utilization. Decision to allocate responsibility of the first round of cost analysis to facilitator originated from the proposal of the Client to speed up and optimize the time used for cost assessment. In addition, it was found beneficial as per the feedback as comparability can be guaranteed best if one person makes the calculation instead of multiple persons. In addition, this approach is aligned with the fact that the process was found to be time consuming by the participants.

As a first activity, the facilitator chooses *relevant cost components* for all the risk scenarios identified both in terms of best and worst case from the cost component list (see appendix 4). This activity represents the step 1 of theoretically based construction 2 and it was found beneficial by the participants of testing. The cost components are marked to the first column of the table 13 showing all the assessments conducted in the total cost of supply chain risk analysis and the familiar example from the previous tables and figures. If there are no suitable cost component available for certain impact of risk or it seems too difficult to evaluate the cost in any other way not included in the list, the non-measured impacts are marked to the second column of the table to be taken into account in interpretation of results which was considered important as per the feedback. It was also noted in the feedback that adjusting the calculations as per the non-measured impact, as was proposed by the literature, was found too difficult to conduct with any valid way so it was decided to be neglected.

Table 13. FMEA analysis table of activity 2 of final construction.

The example scenario is based on real analyzed risk, but the values are changed due to confidentiality.

<table>
<tr><th rowspan="2">Cost components</th><th rowspan="2">Non-measured impact</th><th rowspan="2">Cost of one risk occurrence</th><th colspan="2">Total cost of risk</th><th colspan="2">Average of best & worst-case</th></tr>
<tr><th>EUR</th><th>% of sales plan margin</th><th>EUR</th><th>% of sales plan margin</th></tr>
<tr><td>What impacts of risk scenario should be evaluated?</td><td>What risk impacts were not able to be evaluated?</td><td>What is the cost of one risk occurrence?</td><td>What is the total cost of all occurrences in time frame?</td><td>Total cost vs sales plan margin</td><td>What is the total cost of all occurrences in time frame <u>in average</u>?</td><td>Total cost vs sales plan Margin <u>in average</u>?</td></tr>
<tr><td>Evaluation as per impacts & cost component list of appendix 4.</td><td>Evaluation as per impacts.</td><td>Cost of one occurrence / average of all years if differences as per e.g. sales.</td><td>= Cost of one risk occurrence * Frequency * Time frame</td><td>= Total cost of risk EUR / sales plan margin</td><td>= average of best and worst case</td><td>= average of best and worst case</td></tr>
<tr><td>Worst case
Cost of delivery delays (incl. penalties)

Labor cost of resolving and communication</td><td>Reputation</td><td>1M EUR</td><td>6M EUR</td><td>10 %</td><td rowspan="2">3M EUR</td><td rowspan="2">5,1 %</td></tr>
<tr><td>Best case
Cost of delivery delays

Labor cost of resolving and communication</td><td>Reputation</td><td>20k EUR</td><td>60k EUR</td><td><1 %</td></tr>
</table>

A simple version of costs component list is presented at the appendix 4. The actual calculations in detail, inputs for them as well as clarifying comments included in the actual list are excluded from the appendix to avoid excessive reporting. The changes done to the list are not addressed in depth due to avoid overburdening of the reporting as well, but the cost components added to the ones from literature review in the development process are marked with green highlighting and deleted with red highlighting. In addition, many calculations were developed, but focus is here kept on the cost components again.

The first version of the list was created as per the findings in the literature review and the insight gathered from the cost analysis of case 1. Based on the historical data of case 1, improved understanding of different cost components related to cost component 3 of validation of a new supplier as well as new cost components of investments, extra working and travelling were added to list as they were found relevant. A bunch of reference assumptions of labour costs, travelling and nature of inventory growth as well as general revenue expectation or cost of capital of Client, were also utilized from the analysis. It was also discovered that the realized loss and delay of sales is difficult to evaluate retrospectively if tracking of these changes is not in place when they happen and forecasted demand on business-to-business setting is only delayed but not lost by the risk event. Based on this, evaluation of cost of capital in delays of forecasted sales with possible penalties was established in addition to actual lost customer programs.

After that, a session with two of the experts involved in the testing was organized to develop the list to represent the environment of the Client company. This was also aligned with the proposal of the literature to create and aligned way of total cost calculations. The developed list was used and further developed during and after the testing in cases. As a result of these development steps, the calculations were developed and made clearer and columns for triggering factor of cost component, inputs, calculations and clarifying comments were added to the list. This clarification was aiming to standardize the way of calculations as proposed by the feedback, to decrease the time needed to be used for calculations as well as to restore the documentation of inputs for calculations that was removed from the main tool of table 13 to simplify the tool for analysis. Similarly, the effect of detection and recovery time was included more specifically in the calculations as the pondering of the effect of these measures was removed as separate columns in the tool of table 13 for simplifying but found relevant in the feedback. Additional clarification was also needed for those as the usage in the calculations was found difficult by the author on some occasions.

In addition, as per the analysis and development based on all the three cases, cost components including cost of sales price decrease, marketing costs, insurance, currency fluctuations, higher cost of capital, lost product performance and lost reputation were excluded as they were considered irrelevant in the context or no sufficient way of evaluation was discovered. In turn, the cost components of, for example, increased freight cost, regulatory fines and cost of delivery damage were added based on the testing results. In addition, cost components related to shareholder value were excluded as the Client was a non-listed subsidiary.

As a second activity, after the risk scenarios are matched with the cost components, the *cost of one risk occurrence* is calculated for all risk scenarios based on their best and worst case. This activity like the second step of construction 2 happens by placing the chosen risk components to a standard template of table 14 created for the analysis tool and calculating the cost based on the calculations, inputs, and references of cost component list. On many occasions, certain assumptions must be made by the facilitator to calculate, but they are to be reviewed with the analysis team for validation of results. The calculated costs for both worst and best case are then placed on the third column of the table 13.

Generally, the cost calculations based on expert judgements and reference especially from the case 1 were found only practical way of working without very excessive development work of, for example, simulations. However, the calculations by facilitator were found hard to follow and the breakdown of costs especially in terms of direct and indirect cost were wished to be presented. This led to the creation of standard cost calculation template of table 14 which was also expected to provide standard way that would, again, decrease the amount of time needed to make calculations for dozens of risk scenarios.

The standard table example of table 14 is showing the calculations of the example scenario used in the previous tables and figures, but the values are changed due to confidentiality. In the example, the cost components of cost of delivery delays and labour cost are calculated based on assumption of 1 month of pipeline available in the supplier allocation and 5 percent cost of capital. The delay to customer deliveries is expected to continue during the business recovery time of the best and worst scenario. The detection time difference has no significant effect on cost on this example as tight supply prevents buffer building if single source is assumed. Please note that the penalties create the large difference between the cases as the they are not assumed to occur in short delays. This was also the case with many other scenarios.

The possibility to calculate only the cost of the occurrence if it is same every year is enabled in option 1 marked with red text above the green area of year markings but option 2 is used as the cost of capital of delayed sales changed based on the sales plan. In this option, the average of costs that would occur if risk scenario would occur in different years is used for the total cost of risk calculation.

Table 14. Standard cost calculation template of final construction.

The example scenario is based on real analyzed risk, but the values are changed to protect confidential information.

Worst-case average	Best case average									
1 045 217,75 €	18 447,10 €			Sales plan of example	1 000 000,00 €	1 050 000,00 €	1 102 500,00 €	1 157 625,00 €	1 215 506,25 €	1 276 281,56 €
Worst case										
Average		1 045 217,75 €		Option 1	Option 2					
				Same every year	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6
		Total		- €	1 042 433,33 €	1 043 475,00 €	1 044 568,75 €	1 045 717,19 €	1 046 923,05 €	1 048 189,20 €
Cost component	**Input**	**Input value**								
Cost of delivery delays	Inventory in pipeline after supplier		1							
	Months of delay (BRT-pipeline inv.)		5							
	Lost sales (not included as delay <12 m	**Calculation**		- €	- €	- €	- €	- €	- €	- €
	Penalties (200k per month)	**Calculation**		- €	1 000 000,00 €	1 000 000,00 €	1 000 000,00 €	1 000 000,00 €	1 000 000,00 €	1 000 000,00 €
	Delayed sales revenue	**Calculation**		- €	20 833,33 €	21 875,00 €	22 968,75 €	24 117,19 €	25 323,05 €	26 589,20 €
Labor cost	Months of labor need (from BRT)		6							
	Experts needed (6k EUR)		6							
	Allocation		10 %							
		Calculation		- €	21 600,00 €	21 600,00 €	21 600,00 €	21 600,00 €	21 600,00 €	21 600,00 €
Best case										
Average		18 447,10 €		Option 1	Option 2					
				Same every year	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6
		Total		- €	17 333,33 €	17 750,00 €	18 187,50 €	18 646,88 €	19 129,22 €	19 635,68 €
Cost component	**Input**	**Input value**								
Cost of delivery delays	Inventory in pipeline after supplier		1							
	Months of delay (BRT-pipeline inv.)		2							
	Lost sales (not included as delay <12 m	**Calculation**		- €	- €	- €	- €	- €	- €	- €
	Penalties (not included as delay <3 m)	**Calculation**		- €	- €	- €	- €	- €	- €	- €
	Delayed sales revenue	**Calculation**		- €	8 333,33 €	8 750,00 €	9 187,50 €	9 646,88 €	10 129,22 €	10 635,68 €
Labor cost	Months of labor need (BRT + det time)		3							
	Experts needed		5							
	Allocation		10 %							
		Calculation		- €	9 000,00 €	9 000,00 €	9 000,00 €	9 000,00 €	9 000,00 €	9 000,00 €

As a third activity by the facilitator, the cost of one risk occurrence is turned into *total cost of risk impact* on all scenarios which is the developed version of the third step of construction 2. As can be seen in the fourth and fifth columns of table 13, this is done by multiplying the cost of one risk occurrence with the frequency and time frame of analysis. In the example of table 13, the time frame is assumed to be six years. This kind of total cost of risk cost calculation during the known life cycle of the products in the supply chain was found logical as per the feedback. To provide context for the cost figure, it is divided by the total sales margin of the products supplied by the chain in the time frame that was prepared during the preparational activities of the activity 1. Sales margin was found to be a suitable reference value for the cost of risk impact in the testing, but the reference value should be considered as per the context if applied in other company or industry context.

The further adjustment for the total cost of risk calculation proposed in the literature as per the learning effect, net present value as well as the usage of risk acceptance level for reference were excluded from the final construction as per the feedback received. Learning effect which was already included in the tested version of the analysis tool was not considered to improve the calculation as it was only one possible factor influencing the change in the cost over years in addition to, for example, volume. The net present value calculation was not found important in the business due to low growth of prices and risk acceptance level was considered hard to estimate and even unfamiliar thinking as taking risks cannot be avoided when doing business.

As a fourth activity, the mean of the calculated total cost of worst and best scenario is calculated for the sixth and seventh columns of table 13. After that, the risk scenarios are sorted based on this mean value to form the *initial priority* for the scenarios.

Fourthly, after the initial total cost of risk calculations have been done and the initial priority has been set, they are reviewed in the *120-minute second session of step 3* with the entire analysis team to validate and improve the calculations and priority list. This aligned with the feedback that group working is needed to agree on the evaluations and as well necessary considering the assumptions the facilitator must make solely to provide initial list. Usage of broad amount of time for this step was emphasized by one of the senior managers as well. The session is organized similarly as the first one: preferably in physical setting by projecting the Excel table used to meeting room screen.

First ten minutes of the session are used for going through the working. After that, total of 80 minutes is used for reviewing and fixing the identified cost components, non-measured impact items and, most importantly, the cost calculations and assumptions behind them in the initial order of priority. After this is carried through, the list of scenarios is sorted again based on the fixed total cost calculations and the next 20 minutes is used for going through the evolved priority list and validating that the outcome is reasonable. It is also instructed that the last 10 minutes of the session should be spent on gathering feedback about the process to continuously improve the working and facilitating. As was the case with the first session, extra 30 minutes can be utilized if not all activities are covered in time. This might be the case, for example, if the number of the analyzed scenarios is extensive.

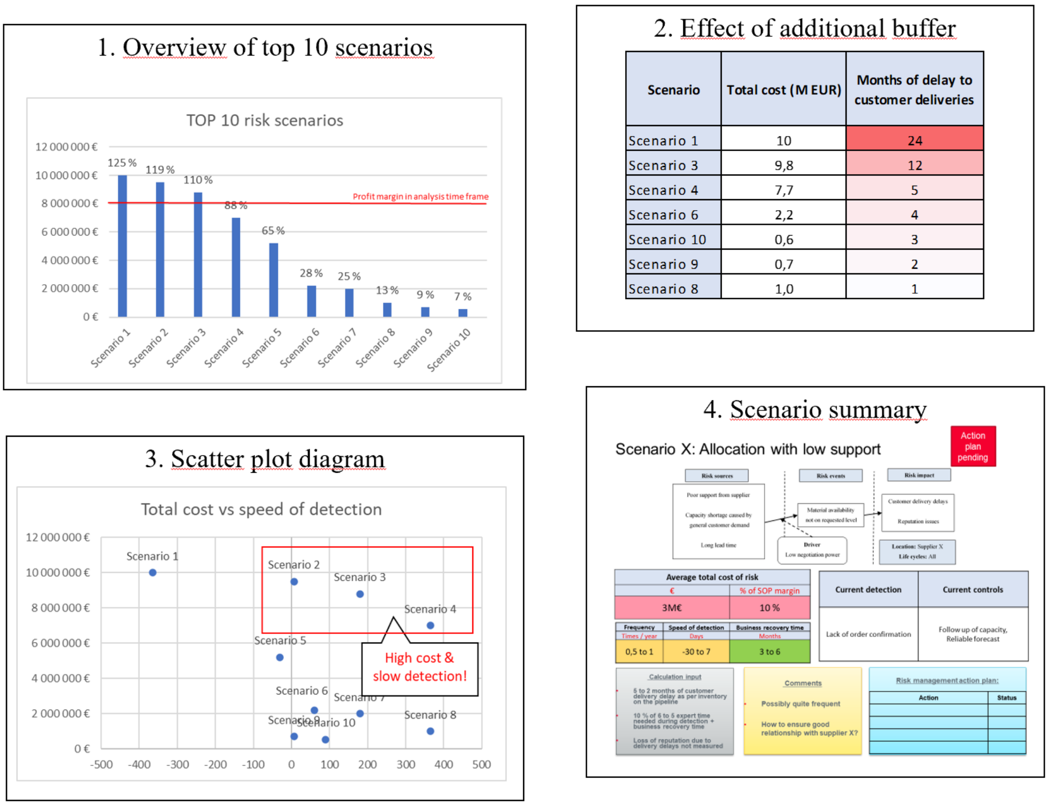

Figure 10. Examples of summaries in final construction.

Finally, after the prioritized list of risk scenarios is validated, the *results of the analysis are summarized* to MS PowerPoint file to function as an input for the risk management action planning for the risks. As with the previous two steps of analysis, the documentation entirely on spreadsheets with additional visualizations was not found adequately even though the user interface of the Excel tool was improved with, for example, conditional formatting for highlighting more extreme values of evaluation from less extreme. Different visualizations used can be found from the figure 10. It should be noted that the separation of scenarios to best and worst-case were only included in developed final constructions after testing and, thus, similar visualizations require usage of mean value in visualizations to provide reasonable insight.

The summary of the testing round was provided by, firstly, by creating overview of the total costs by emphasizing the top 10 scenarios as per the priority (see visualization 1 of the Figure 10). Key themes to focus on SC risk management based on the content of these scenarios was provided as well but it was also highlighted that the priority is not absolute as there is lot of uncertainty and assumptions in scenarios and the calculations. In the testing, the scenarios with highest total cost were mostly related to poor relationship with supplier base, geopolitical risks and natural disasters, problems in supplier selection and validation especially related to technological match, demand variation and forecast errors as well as IP issues. The results also indicated that the analysis was mostly including and highlighting risks from upstream rather than downstream of the supply chain.

Secondly, in addition to the overview of the scenarios, insight for general issues of SC planning were also provided by analyzing how much buffer stock could help to avoid certain risk scenarios inspired by a similar analysis of Canbolat et al. (2008), how much risk cost is related to single sources in the SC and from what tier of the SC does the greatest average risk originate from. The buffer stock analysis can be found from visualization 2 of the Figure 10. Again, it was emphasized that lot of uncertainty is involved and, thus, further analysis is essential.

Thirdly, the risk scenarios were analyzed based on the two axis scatter plot diagrams based on the evaluations of cost, frequency, speed of detection and recovery time. A scatter plot diagram example of total cost and speed of detection can be found from visualization 3 of the Figure 10. This approach was originating from the traditional severity–occurrence diagrams that were noted to have been utilized by some of the participants in other contexts. This analysis provided insight about scenarios that, for example, possessed total cost but couldn’t be identified beforehand and thus, could, benefit from detection methods for earlier detection and stronger controls to avoid them entirely. It also seemed that in both cases, the risk scenarios with highest cost were mostly expected to happen not more often than only once in the analysis time frame.

Finally, a summary of each of the scenarios were included in the presentation. For top 10 risks, all the evaluated insight was included in the summary with highlights for more extreme values, whereas for scenarios with smaller total cost, the risk scenario visualization and total cost were included. A summary for a top 10 risk scenario can be found from visualization 4 of the Figure 10. For all the summaries, comments about the inputs and assumptions of the analysis as well as the key themes to consider in action planning were included. Furthermore, a table for risk management actions with status follow up for individual actions and entire plan for mitigating risk scenario were added. Despite a feedback item that the proportion of the sales related and other cost of risk impact should be communicated in the summary, this was not included in the summaries to limit the time for analysis needed in testing. In addition, the information is difficult to extract from the cost calculations as they are mostly based on averages of different years of occurrence with different proportions of cost components.

6.5 After analysis step

The actual analysis process of the final construction ends to the list of prioritized supply chain risk scenarios and summary of the results. However, it was considered logical to the author to include certain items of instruction for the utilization of the results of the analysis and other post-analysis activities. These include archiving, update of the tool, risk management action planning and periodical reviews of supply chain risk analysis.

Firstly, the *archiving of analysis materials* including MS Excel spreadsheets and MS PowerPoint slideshows was instructed to be done to suitable location which could be, for example, SC development project folder. This was considered important for revisiting the analysis for updates or for benchmarking to support analysis of other supply chains.

Secondly, *the classifications of risk sources, impacts, drivers, and cost components should be updated* if new insight emerges throughout the process. This activity together with the archiving was inspired by the viewpoints of Ellram (1993a, 53–54) about the documentation of the total cost calculations so that there is no need to 'reinvent the wheel' every time. This enables, as well, the continuous learning in supply chain risk management efforts as the knowledge gathered in the analysis is spread to future analyses via development of the model. The continuous improvement of the model is highlighted by Ellram (1993a, 72) as well in addition to Ellram and Siferd (1998, 72).

Thirdly, *the risk management action planning* should be conducted based on the analysis. Even though the actual risk management strategies are not in the scope of this thesis, the two main inputs from the analysis process to action planning should be noted. As a first input, the prioritization of supply chain risk scenarios as per the total cost might enable finding focus to most important and effectful risks as well as the cost-benefit analysis of the risk management strategies as proposed already in the literature review. As a second input, the different evaluations of scenarios might trigger new viewpoints to risk management actions. For example, long business recovery time might point out a need for actions enabling quicker resolution of realized risk scenario. As another examples, slow detection might inspire to develop improved detection methods and the actions might aim to eliminate or mitigate the sources, drivers, or impacts. In addition, lacking detection and control methods might lead to actions of developing such methods. As the actions and responsibilities for their execution are planned, the action plan tables in risk scenario summaries created in step 3 should be updated accordingly for documentation and communication purposes.

Finally, *the periodical review of the risk analysis* proposed by the literature is the final action of after analysis step. The periodical reviews to 'capture changes or progressions' were found beneficial by the participants of testing, but the actual content was not very clear initially. However, support from management and resource was noted to be essential for the execution. The periodical review cycle and content was further discussed with the senior manager of the company and following rule of thumb was developed: The entire analysis including SC map, risk sources and risk scenarios as well as evaluations and calculations should be updated twice per year. However, the SC context should be considered and the time for revisiting analysis could be, as well, when significant changes occur in supply chain or when life cycle phase of the products supplied through the chain changes. In addition, lighter status update of risk management actions should be periodically reviewed, per se, once per quarter.

7 DISCUSSION & CONCLUSION

In this final chapter of the thesis, the *key findings* of the study are concluded, and *theoretical contribution* is generated by comparing the results of the empirical study with the theoretical knowledge as highlighted by the seventh step of the CRA process. Furthermore, *managerial implications* are reviewed to establish the relevancy to the potential users in practical business setting. Finally, the *key limitations* of the study and the scope of applicability of the construction as per the sixth step of the CRA process followed by the *future research* opportunities are discussed to reach the level of criticalness required of a CRA study (see Lukka 2000, 12–13).

7.1 Summary of key findings

As the theoretical background for the constructions 1 and 2 was established in the chapters of literature review and the constructions were tested and further developed to final construction in the empirical study, following eight key findings related to the two research questions of the study – four key findings per each – have been generated in the process.

7.1.1 Research question 1: How can the supply chain risk impact be identified?

The first key finding of the study is that the targeted construction of the study, supply chain risk analysis tool and way of working focusing on the impact of risk, can indeed be generated, and developed based on the set of tools inspired by, for example, Kwak et al. (2018, 375) and Canbolat et al. (2008): analysis of systematic risk identification with risk mapping, cause-and-effect analysis for creating risk scenarios and FMEA for analyzing and prioritizing the scenarios.

Key finding 1: *The supply chain risk analysis tool for identifying and analyzing risk scenarios leading to impact of risk can be constructed based on risk mapping, cause-and-effect analysis, and failure mode effects analysis.*

The way of working based on the three tools was found to provide a broad view of the supply chains risks as per the feedback of the testing, the logic of tools was found suitable with the tasks in hand and, especially, the FMEA providing relevant results for the decision-making based on the monetary prioritization of risks. However, the actual risk scenarios identified were considered quite standard and lack novel findings that would have created totally undiscovered and unexpected risk insight. Furthermore, issues about the time-resource required and complicatedness of following the results were highlighted. Although, some remedies for these flaws were developed to the final version of the construction. Thus, the second key finding is formulated as follows:

Key finding 2: *The supply chain risk analysis tool constructed seems to provide broad view and relevant insight for decision-making but lacks novel findings and suffers from high time-usage and complicatedness.*

The third key finding is related to the holistic approach to the supply chain, risk and total cost proposed by various authors (see Manuj & Mentzer 2008a, 133; Rao & Goldsby 2009, 101, 115; Vilko & Hallikas 2012, 593; Kwak et al. 2018, 375; Ellram & Siferd 1998, 55). Despite, the construction being praised for its broad view and holistic approach to risk structures and cost components providing depth to the working, the tighter scope of analysis including only risks not handled by other business processes as well as identification of risks specific for the analyzed chain were highlighted in the feedback and development of the construction to increase relevance of results.

Key finding 3: *The holistic view to risk and supply chain is found enriching in the supply chain risk analysis but will to limit the focus of the analysis to increase relevance sets boundaries for comprehensiveness.*

As a fourth key finding, difficulties of running through all the three steps of analysis in the remote working mode driven by Covid-19 restrictions were highlighted in the feedback. Even though this feedback might be influenced by the facilitation skills of the author, it raises the question whether the basic tool design created during pre-pandemic era is bound to change in the new way of working with increased amount of remote working. Physical working whenever possible was recommended in the final construction based on the feedback.

Key finding 4: *The tools of the supply chain risk analysis from the pre-pandemic era might face challenges in the remote working environment driven by global pandemic.*

7.1.2 Research question 2: How can the total cost of supply chain risk impact be assessed?

As the fifth key finding and first related to the research question 2, it is highlighted that it was indeed possible to construct a way of assessing and prioritizing supply chain risks based on the key principles of total cost of ownership: comprehensive view to cost via wide list of cost components, life cycle approach to cost via total cost of risk calculation based on frequency of risk as well as consideration of indirect cost in calculations via utilizing labour cost estimates in calculations (see Ellram 1993b, 4; Ellram 1994, 171; Ferrin & Plank 2002, 29; Hasan et al. 2020, 26).

Key finding 5: *The supply chain risk analysis tool for assessing and prioritizing the risk impact can be constructed based on principles of total cost of ownership.*

The way of working of the supply chain risk analysis tool that focused on the prioritization of the FMEA risk scenarios based on the cost estimates similarly as, for example, Canbolat et al. (2008, 5154–5155) and TCO thinking was found beneficial, systematic, and concrete as well as providing relevant results for the supply chain related decision making. However, the main criticism towards way of working was related to the difficulties to follow and thus, possibly interpret the calculations behind the total cost of risk assessment and prioritization.

Key finding 6: *The cost calculations and prioritization of risk based on monetary values and TCO was found to provide relevant results, but the calculations under the bonnet can be difficult to follow.*

Seventhly, the proposal to emphasize the impact of risk instead of probability of risk in the supply chain risk assessment advanced by Mitchell (1995, 116–117), Cousins et al. (2004, 557–558) as well as Norrman and Jansson (2004, 446) due to difficulties in estimating probability as well as better managerial relevance of impact seemed to trigger two-fold reactions in the testing. On the one hand, the prioritization based on cost figure as well as the replacement of likelihood with more time-bound measure of frequency presented as a risk component by Manuj and Mentzer (2008b, 196–197) were found to beneficial by the participants based on the feedback. On the other hand, the assessment of occurrence was proposed many times during the testing process and the consideration of probability in the follow-up of scenarios was also proposed after testing. In addition, most of the scenarios with highest priority were considered to happen only once in the analysis time frame which is influenced by the high impact of customer delays to risk impact cost but also indicate that the prioritization could have been different if probability would have played larger part in the analysis. Furthermore, traditional severity-occurrence diagrams were mentioned as insightful visualizations from other risk analysis contexts. As a conclusion, the seventh key finding is composed as follows:

Key finding 7: *The prioritization of scenarios based on cost and frequency instead of impact and probability was found beneficial, but the practitioners do not expect the consideration of probability to be neglected entirely in supply chain risk analysis.*

The last key finding is related to the usage time-related measures of speed of detection proposed by Manuj and Mentzer (2008b, 196–197) and Wu et al. (2007, 1860) as well as the business recovery time advanced by Norrman and Jansson (2004) and Simchi-Levi et al. (2015, 377) instead of scale-measures for difficulty of risk measures and control utilized by, for example, by Tuncel and Alpan (2010, 253). Generally, the usage of different measures for risk analysis was found to be a good practice in the testing feedback and absolute time-related values were found easier than usage of scales measures. However, the usage of especially the speed of detection in the cost calculations was sometimes difficult if no possibility for buffer building to counter upcoming shortage of supply was available and, thus, the usage of measures was clarified in updated cost component list. Nevertheless, it can be noted, that the view of Bandaly et al. (2012, 253) about the irrelevancy of the detection of risks in supply chains seemed not to gain support in the testing.

Key finding 8: *The usage of absolute time-related measures instead of relative scales was found a good practice in the supply chain risk analysis tool.*

7.2 Theoretical contribution

The theoretical contribution of the study is reviewed in this subchapter by, firstly, discussing the contribution provided for the research gaps identified in the beginning of the thesis. After that, in addition to key findings of the study, the feedback about the theoretical proposals behind the construction is linked to the theoretical knowledge to further illustrate and refine the theoretical viewpoints as per the classification of theoretical contribution of CRA studies of Lukka (2000, 7–9). This review is as well divided based on the two research questions of the study. It should be however noted, that due to low number of people per testing step, usually around five, involved as well as low number of cases and lack of additional company context, the generalizability of the theory testing and possible new theory can be limited without further validation (see Lukka 2000, 7–9).

7.2.1 Contribution to research gaps

Research gap 1: *Development of tools to measure costs and benefits of SCRM*

The development of tools for quantifying the cost-benefit relationship between the SCRM strategies and supply chain risks highlighted by various authors including, for example, Colicchia and Strozzi (2012, 414), Khan and Zsidisin (2012), Ho et al. (2015, 5061) as well as Fan and Stevenson (2018, 222) and Pettit et al. (2010; 2013) was existing on practical problems of Client company as the means to provide the monetary assessment of supply chain risks to justify the business case for counter-measures were sought. This linkage laid a fruitful basis for theoretical contribution for this research gap.

As a main contribution, the supply chain risk analysis tool capable of monetary evaluation of risk impact was developed and the main working logic, instructions as well as supporting tools were presented in the results section of the study. Even though the actual usage of cost estimates in actual cost-benefit analysis was not tested as it would have been out of scope of the actual construction, the insight was anticipated to provide concrete evidence for improved supply chain risk related decision-making based on the feedback.

Research gap 2: *Robust and systematic tools for risk identification and assessment*

The development of tools for risk identification and assessment which should be robust and systematic as well as take into account the interconnection of risks has been highlighted by Colicchia and Strozzi (2012, 412, 414). The main aim of these efforts is to improve the prioritization of risks for efficient resource allocation to risk management (Gaudenzi & Borghesi 2006, 114; Hajmohammad & Vachon 2016, 59; Fan & Stevenson 2018, 215).

As a main contribution to this research gap, a way of working with detailed workflow of the supply chain risk analysis tool enabling the prioritization of risks based on the evaluated cost of impact was developed in the constructive study. The systematic approach of the way of working was acknowledged in some of the feedback items as well. The interconnection of risks was considered in the cause-and-effect analysis as the linkages of multiple sources and impacts to risk event was encouraged. However, the interconnection of different risk scenarios to each other was left out of the scope of the tool to avoid excessive complexity. The robustness of tool was strengthened by providing standard way of working via standard spreadsheets, classifications, calculation templates and cost components. However, the robustness might be seen to be decreased by reliance on evaluations rather than simulations standard mathematical models as well as significant role of facilitator which might decrease the consistency of analysis. In addition, working on MS Office environment instead of more specialized and integrated software environments might decrease the robustness of tools as well. However, both decisions were necessary due to limited resources in terms of time and author expertise natural for a thesis project. In addition, linking the tools to the Client information systems for data extractions was not found to provide much additional value as per the feedback of the testing.

Research gap 3: *Application of total cost of ownership thinking to SCRM*

The strengthening of connection between the SCRM and TCO literatures had been proposed by multiple authors of the field including Zsidisin et al. (2000, 196), Rao and Goldsby (2009, 115–116) as well as van Hoek (2020a, 351–352). However, limited number of applications seemed to have existed in the literatures so far as recognized in the literature review.

The main contribution for this research gap is the risk assessment, prioritization as well as supporting cost component list of the SC risk analysis tool based on the principles of TCO including focus on monetary evaluation, indirect cost consideration and life cycle cost thinking. This contribution represents the greatest novelty of the thesis for the academic literature as well due to limited number of studies integrating SCRM and TCO approaches. However, firstly, as the total cost calculations were mostly composed by the author, secondly, as the participants of the testing reported difficulties on following the calculations, and, thirdly, as the relevance of the results to actual decision-making was purely based on assumptions, the further validation of the total cost calculation feasibility in the actual SCRM decision-making constitutes an interesting future research opportunity not entirely covered in the scope of this thesis.

Research gap 4: *Further validation of SCRM concepts with empirical methodology*

The importance of further empirical testing of conceptual models of SCRM as well as investigating the practitioner ways of SCRM activities had been highlighted by various authors of the SCRM field including Harland et al. (2003, 55), Colicchia and Strozzi (2012, 414) and Ho et al. (2015, 5060). In addition, the execution of research in different industry contexts had also been highlighted by Jüttner et al. (2003) and Fan and Stevenson (2018, 222).

The main contribution for this research gap was provided by developing a construction based on the theoretical concepts about SC flow diagram, systematic SC risk identification, CEA, FMEA as well as TCO approach and further testing and developing the construction in empirical setting. However, due to a unique combination of concepts, heavy development of activities during the process and limited number of participants in testing, cases and company contexts, absolute support or objection towards specific concepts cannot be presented with confidence and the testing should continue in other contexts as well. Important contribution for the gap as well as novelty of the thesis is the application of CRA approach in SCRM and TCO contexts which seems not to be oversaturated territory, at least, based on academic journal articles. Furthermore, due to unestablished status of the CRA approach in the business research community as per to Lukka (2000, 12–13), the number of CRA studies are hardly extensive at any contexts. Finally, as for the contribution for industry context, the in-depth review of industry characteristics was left out of the scope of the thesis. However, especially the developed classification of the appendices 1 to 4 might reveal insight especially relevant for industry specific research as well as they were developed based on the relevance in Client company context.

7.2.2 Theoretical proposals related to research question 1

In addition to the key findings reviewed, the insight about different viewpoints and proposals from literature is compared with the results received in testing. Thus, the theoretical contribution is strengthened. In this subchapter, the focus is on theoretical insight related to research question 1. The general proposals related to comprehensiveness of analysis and life cycle thinking are reviewed first. They are followed by proposals specific to the three steps of working: supply chain risk mapping, cause-and-effect analysis as well as failure mode effects analysis.

In addition to key finding 3, additional insight related to the *comprehensiveness of analysis* were emerging based on the testing. The wide scope of different parties and countries of supply chain proposed by Manuj and Mentzer (2008a, 133) was found relevant in the working and wide set of different known parties of the chain including, for example, packaging suppliers, was instructed to be included. The viewpoints of Rao and Goldsby (2009, 101, 115) about the need to include wide set of functions in the working was found important, as the stronger presence of sales function was requested by participants and the absence in most of the steps might have led to the situation that the coverage of identified risks from downstream of the chain was low. Cross-functional working has been emphasized by Canbolat et al. (2008) as well. However, Rao and Goldby's viewpoint about the target to optimize the outcome for the entire supply chain, a similar viewpoint to the one of Ellram and Siferd (1998, 55) about cost target of supply chain management, seemed to influence the testing to less extent: The calculations were focal company centric, and the consideration of different parties impacted was not found very relevant. However, the low visibility and the facilitation of the author might have steered the focus out of the total supply chain cost as well. Furthermore, the inter-organizational involvement highlighted in both SCRM and TCO literature was found relevant in the level of information sharing but involvement to actual working was not found beneficial mainly due to confidentiality.

As another viewpoint of more general terms, the proposal by Canbolat et al. (2008) to consider the difference between the risk scenarios in different *life cycle phases* seemed to resonate well as per the feedback and the consideration of life cycle phase was instructed to be included in various steps of working in the final construction – even though it was not utilized in the testing phase widely. Changes in product life cycles were considered in the timing of the analysis as well.

Related to the first step of the analysis process, *supply chain risk mapping*, the usage of SC map for risk identification featured in the work of, for example, Harland et al. (2003, 56–59), Norrman and Jansson (2004), Rao and Goldsby (2009, 115) as well as Tummala and Schoenherr (2011) was supported in the testing and usage of the map in other SC planning contexts as well was encouraged as per the feedback. The identification of risk sources proposed by Jüttner et al. (2003, 201) was found logical by the participants and the tailoring of the supply chain risk classification based on the context advanced by Blackhurst et al. (2008, 148–149) seemed to exist in the working as flexibility to add items to the classification was noted in the feedback. The controllability of the risk proposed by, for example, Wu et al. (2006, 351–353) was found irrelevant in the step 1 of the working but it was later commented that the controllability should be pondered when risk management actions are planned.

As for the second step of the working, *cause-and-effect analysis*, the usage of CEA discovered by Sanchez-Rodrigues (2010) and Kwak et al. (2018) as well as utilization of scenario planning by Gaudenzi and Borghesi (2006, 118) in risk analysis was found logical but challenging by the testing participants which could be related to the remote working as well in addition to the number of risk components in the working. A structure change of the working was proposed as well in the feedback which might reflect the difficulties in working as well. In addition, the visualization of the results proposed by Kwak et al. (2018) and Gaudenzi and Borghesi (2006) was found important in the feedback. The identification of the risk drivers proposed by Jüttner (2003, 201) was found to provide more content to analysis, but the activity was not easy to conduct for many of the risks. Furthermore, the risk drivers and risk impact drivers reviewed separately in the literature review were combined in the final construction to simplify analysis.

Finally, related to the third step of the working, *FMEA*, the usage of failure mode analysis advanced by Canbolat et al. (2008), Tuncel and Alpan (2010), Tummala and Schoenherr (2011) as well as Kwak et al. (2018, 375) was acknowledged in the testing especially due to its ability for comparison of different risk scenarios but the complicatedness and required time resources were found problematic. The FMEA as a tool was also familiar to many of the participants due to automotive industry context similarly as in the case of Canbolat et al. (2008). In addition, the identification of impacted parties by the risk as per the thinking of Christopher and Lee (2004, 393) and the allocation of responsibilities for managing the risks in FMEA working proposed by Canbolat et al. (2008, 5151–5152, 5158) were not found relevant in this phase. The determination of responsibilities, however, were instructed for the risk management action planning to ensure effective execution of actions.

7.2.3 Theoretical proposals related to research question 2

The summary of the feedback for theoretical proposals related to the research question 2 and the cost assessment of the risk impact is started with theoretical proposal of challenges of TCO and counteractions for them, continued with proposals related to measures as well as cost components and ended with viewpoints related to documentation and proposed additional analysis activities.

Firstly, related to the *challenges of TCO* proposed in the literature, the complexity and high resource need of data collection for the calculations proposed by Ellram (1994, 175–176) as well as Ellram and Siferd (1998) was aligned with the feedback: The calculations were considered difficult to follow, the overall activity time-consuming and as the calculations took significant time from the author to prepare.

The challenges of integrating the more qualitative cost drivers to the TCO approach noted by Ferrin and Plank (2002, 26) was acknowledged and solved by making comments about non-measured risk impacts for the risk scenarios which was considered to be an important activity. However, the adjustment of calculations based on the more qualitative items proposed by Knemeyer et al. (2009, 148–149) did not gain support from the participants due to difficulty of such action.

The challenges of data sharing in the SC highlighted by Hassan et al. (2020, 26) were possibly leading to the focal company centric calculations and the lack of data about, for example, new supplier relationships noted by Ellram (1995, 21) was tackled based on reference from the case 1 or with other expert evaluation which can be seen as a relative of conservative convention proposed by Ellram. In addition, the usage of expert judgements and references for the calculations was found to be only reasonable way of working in the context by the participants of the testing.

Actual cultural challenges when implementing TCO proposed by Ellram (1994, 175–176) as well as Ellram and Siferd (1998, 68–71) were not identified directly related to the TCO. However, the lacking ways of working of, for example, working capital, labor cost and sales loss calculations increased the amount of workload needed.

Secondly, as for *the ways to tackle issues of TCO*, the proposals of Ellram (1994, 188) and Ellram and Siferd (1998, 72) of sensitiveness to issues, cross-functional co-operation, top management support and training seemed to resonate well in the testing: Sensitiveness to issues was ensured by collecting feedback, cross-functional co-operation was found important in the working, top management support was aimed to be achieved by analyzing only significant supply chains and, finally, the training material in the form of comprehensive instructions were encouraged to be composed. The development of 'the right model' before wider implementation by Ellram and Siferd (1998, 72) was also found beneficial via testing and development of the constructive study.

The usage of automated data collection proposed by Ellram and Siferd (1998, 68–71) to tackle issues with data collection was not found beneficial by the participants due to IT resources and relevance of available data but the calculations and cost components were made more standardized to reduce the time resources required.

Furthermore, the focus of TCO efforts firstly to non-repetitive transactions with high significance and creation of criteria for TCO implementation to gain sufficient benefits from the analysis – viewpoints advanced by Ellram (1993a, 53; 1994, 187–188) and Ferrin and Plank (2002, 23) – was found relevant. In addition, the core application area of the tool was determined to happen in supply chain cases with significant revenue impact.

Thirdly, in addition to the key findings of special insight 7 and 8, certain *measure-related insight* interconnected with the theoretical proposals emerged. The usage of the risk cost in the entire life cycle or time frame analysis similarly as Canbolat et al. (2008) received positive feedback from the participants. This can be seen to strengthen the relationship of SCRM and TCO as life cycle cost is in the center of TCO thinking as well (see e.g. Ellram (1993b, 4). In addition, the consideration of learning effect as well as the net present value (NPV) was proposed to be included in the total cost of risk calculations by certain studies (Canbolat et al. 2008; Berle et al. 2013, 257). However, neither of these two considerations were found relevant by the participants due to wide amount of other factors impacting the total cost for learning effect and low growth of prices for NPV.

Fourthly, as for *the cost components of the risk impact*, the mutually agreed measurement system proposed by, for example, Harland et al. (2003, 52–53) and the selection of 'core' cost components for the TCO model by Ferrin and Plank (2002, 18, 26–27) was pursued by developing the list of cost components co-operatively before the testing. The identification of 'specific' components by Ferrin and Plank for the scenarios from the more general 'core' list was found beneficial by the participants. Sufficient way of calculation was not identified for many of the risk impacts like, for example, social and psychological loss, as per the literature review. Some additions including investments cost, procurement price and different logistics related costs were added but many of the risk impacts remained without sufficient way of calculating after the development as well.

As for specific cost components, the sales impact of supply shortages was found to be a significant component but difficult to assess especially retrospectively. This is aligned with the thinking of Harland et al. (2003, 53) who considers it highly challenging to assess due to large number of intangible aspects. However, the identified importance of the sales effect in total cost calculations seems to be aligned with the thinking of van Hoek (2020b) who highlight the importance of revenue and customer satisfaction due to the effects of Covid-19 leading to availability issues. In addition, the concept of cost of capital was integrated to the cost of delayed sales impact in addition to the penalties to reflect the lower level of capital available to gain revenue for. Furthermore, the costs of redesigning and reallocating the supply chain proposed by, for example, Silbermayr and Minner (2016, 228) as well as Mori et al. (2017, 90) seemed to be quite significant in the calculated risk impacts. This is possibly driven by the good coverage of the case 1 cost components from related incident as well as the large effect of linked sales impact due to long validation times. Finally, certain cost components, including shareholder value and sales price proposed by Hendricks and Singhal (2003, 503–504; 2005a, 696), insurance premiums by Norrman and Jansson (2004) as well as currency fluctuations by Bogataj and Bogataj (2007, 292) were not found relevant enough to be included in the cost component list in the Client company environment. This was caused by Client company being non-listed company and lack of historical record for insurance premium increases and currency exchange rate changes driven by risk events.

Fifthly, related to *the documentation efforts* of the risk analysis, the archiving and continuous development actions were instructed based on the viewpoints of Ellram (1993a, 53–54). In addition, the efforts of summarizing and visualizing the results in addition to basic MS Excel spreadsheets was heavily featured in the feedback of the testing. This is aligned with the work and proposal of, for example, Norrman and Jansson (2004) and Canbolat et al. (2008) and Vanany et al. (2009, 25–26) who all present different ways of visualizations and summaries of the supply chain risk analysis.

Finally, different *additional analysis activities* to enrich the results which were not included in the tested construction to avoid excessive complicatedness were proposed by the literatures of TCO and SCRM to improve the relevance of results. These activities received varying feedback from the participants of testing: The ‘risk acceptance criteria’ proposed by Berle et al. (2013) to determine accepted level of risk was not found to be suitable with the Client company risk perception. However, a bit similarly, the total cost of risk impacts figure was compared with the expected revenue margin from the supply chain to provide context for the results. In addition, the calculation of the cost of resources allocated for risk analysis proposed by Kleindorfer and Saad (2005) as well as Hou and Zhao (2020) was not recommended to be executed directly by the feedback, but the criteria for significance of analyzed supply chains was reflecting a similar way of thinking. The sensitivity analysis for cost calculations advanced by Ellram (1993a, 53, 55) seemed to resonate well in the testing as the splitting of the risk scenario evaluations to best-case and worst-case scenarios was strongly proposed by the feedback. Finally, as another supported activity, the periodical review of results based on the thinking of Ghoshal (1987) and Blackhurst et al. (2008, 144) about changes in risk environment was encouraged in the feedback to be implemented to the supply chain risk analysis tool.

7.3 Managerial implications

As the primary managerial implication of the study, a final construction of *supply chain risk analysis tool* for identifying the supply chain risks in analyzed supply chain as well as assessing and prioritizing them based on the monetary impact was developed with detailed workflow and examples described in results section. In addition to risk analysis, this construction could see managerial usage to support the selection and cost-benefit analysis of risk management strategies as well (see e.g. Kleindorfer and Saad 2005, 55).

From the perspective of the Client company, this construction together with the detailed instructions for the usage provides a remedy for the difficulties in identifying and assessing the risk impacts existing in their supply chain structures in monetary terms. Furthermore, the Client company have received an in-depth analysis of realized risk event of case 1 as well as risk analysis of upcoming supply chain of case 2 and supply chain in implementation of case 3 as requested. In addition to the construction and risk insight, few recommendations for SC management and cost analysis based on the case 1 was provided for the Client company which are not to be published due to confidentiality and lack of review of the cost analysis results of Case 1 in the thesis report.

As another managerial implication, *the risk and cost component classifications* of appendices 1 to 4 might provide a basis for the risk management analysis conducted in the other companies especially related to manufacturing in sectors of semiconductors and automotive. This implication exists as the classifications were developed based on the relevancy and the insight from the Client company environment.

As a third main managerial implication, few interesting considerations can be extracted from *the key findings of the study*: Firstly, the monetary evaluation of the supply chain risk impact as well as usage of business-related measures instead of relative scales received strong support in the testing and, thus, might turn out to be a beneficial activity in SC risk analysis for wider managerial audience as well. Secondly, the issues of remote working in the collaborative SC risk management activities might call for reconsidering and reiterating current ways of working when applied in the remote environment. Thirdly, finding a balance between comprehensiveness of analysis and scope for relevance of results as well as the highlighted need of summarizing and visualizing the risk analysis results suggest important guidelines for the risk analysis efforts of practitioners.

Finally, *the CRA research* despite its demanding nature proved once again to provide both solutions and substance for the target organization together with theoretical contribution for academic community. Thus, CRA could be recommended for the organizations seeking solutions for their practical managerial issues of SCRM with strong theoretical background and benefit to the wider society and industrial community around them.

7.4 Limitations

In this final sub-chapter of the thesis, the limitations related to applicability of the construction and results in other contexts are reviewed. This is executed by analyzing the detailed weak market test proposed by Labro and Tuomela (2003), by reviewing the feedback gathered in testing, and, by defining the limitations generated by the research design and the context of testing environment in Client company.

Table 15. Weak market test results of supply chain risk analysis tool.

X = Current status evaluated by author
X = Perceived potential status evaluated by participants (n = 2)

		The **extent** of usage (how often* used in organization based on potential)				
		One person (personal tool)	Team (e.g. Sourcing)	Business unit (Client)	Division (Parent division)	Entire organization (Parent company)
The **intensity** of usage (how often used in organization based on potential)	Regular use replacing old system(s)					
	Regular use in parallel with old system(s)					
	Ad hoc usage			XX		
	Used once		X			
	Tried once but not actually used					
	Rejected after Unsuccessful implementation trial					

Strength of the pass

* Spelling mistake in the table used in the session. Should state widely, not often.

Firstly, according to the Labro and Tuomela (2003, 430–431) the truthfulness of the construction is demonstrated by passing *the weak market test* if the construction is used at least once (grey area) by providing actions in the target organization (see Table 15). The status of the construction evaluated in the table 15 by the author as of the date of the writing of this subchapter is that the construction has been tested in two supply chains in team level working and results have been planned to be used in actual supply chain risk management action planning in, at least, one of these two supply chains. Even though there is still uncertainty about whether the action planning is generated, based on the current status and general feedback about the construction it seems likely that the minimum pass of the weak market test is reached and, thus, the actual working of the construction is demonstrated. For example, in supply chain case 2, the results were decided by the supply chain project team to be utilized for risk management action planning in a bit later phase of the project when more unclear items were clarified in the supply chain design.

In addition, similarly, as was inquired by Ihrig et al. (2017, 228) in their CRA study, as the visibility to the actual usage of the construction is low due to short time span of the thesis project, two of the participants in the testing evaluated that the potential of the construction could be in ad hoc usage in business unit wide usage of SCRM activities (see Table 15). This might strengthen the pass of the weak market test. The reasons for the evaluation can only be speculated, but it is possible that the high resource need – 10 to 15 hours of group working in addition to individual activities of the facilitator – might limit the intensity and the low level of integration with division and parent company operations the extent of usage. This insight might as well constitute the first limitation for the extent and intensity of utilization of the construction if similar contextual factors are present. However, it should be noted that low number of respondents for the weak market test leaves room for possible other opinions amongst participants of the testing.

Secondly, *the feedback gathered* from the participants of the testing reveals additional possible limitations for the constructions and results of the study related to scope of applicability. It was noted by participants that the construction could be suitable in other life cycles of supply chains as well in addition to early life phase of the tested chains. It was also interpreted by author from the feedback that that similar set of tools could see usage in other usages related to business and technology risk and that common methods with risk analyses of other business processes should be pursued. However, the high enough level of significance of the analyzed objects due to heaviness of the analysis was seen as an important precondition for the applicability of the construction in other arenas.

This limitation is well aligned with the feedback of simplicity and easiness of usage appearing in many steps of the analysis about the large resources taken which seems to be natural for TCO-based models as well (see e.g. Ellram 1994, 187–188; Ellram & Siferd 1998, 63, 68–71; Ferrin & Plank 2002, 23). Furthermore, this might limit the applicability of the construction in the organizations with more limited resources than the Client company operating with over 1 000 employees in Finland. Finally, additional limitation for the applicability might be created by the issues with relevancy of the results related to the lack of novelty or surprisingness of the risks identified. On the one hand, even though the value of the constructions lies elsewhere as well – especially in the prioritization of the risks based on monetary impact – this might limit the value provided by the analysis especially if conducted in supply chains that are already in more mature phase of life cycle and, thus, the risks of the supply chain are better known. On the other hand, the cost analysis might be better informed in more mature supply chain and application to other life cycles was especially proposed as per the feedback of the testing.

Thirdly, certain limitations can be derived from *the research design of the thesis* in which the construction was tested and developed. General issues of high involvement of Client company personnel, short time span of the analysis, promotion of interests as well as observer bias and issues of generalizability of CRA studies identified in the chapter of research quality might limit the generalizability and reliability of the results in other contexts (see Kasanen et al 1993; Labro and Tuomela 2003).

In addition, the reporting of the supply chain risk results is not extensive in the study due to confidentiality reasons and the researcher experience of the author in CRA demanding high involvement of the researcher as noted by, for example, Lukka (2000, 2) is limited. These factors might set limitations for the quality of the results and, thus, also for the applicability if tested in other contexts. Furthermore, as the thesis is focusing on supply chain cases of one company and the number of participants of testing is limited to around five in most parts, the results of the thesis are hardly a comprehensive view. However, the generalizability of the CRA study does not lie in the large samples but in the functionality of the construction as noted by Kasanen et al. (1993, 259–261). In this study functionality was assessed based on the feedback of the testing and the results of the weak market test and considered, thus, to be at least promising with certain reservations.

Finally, the certain characteristics in *the business and industry environment of the Client* might limit the applicability. In addition to the resource related considerations, the Client company operating from a stable society of Finland might change the risk landscape significantly in comparison with companies from more unstable regions geopolitically. However, due to international supply chain environment, the difference with other international supply chain actors might not be that crucial.

The extensive life cycles of the products of the Client company of usually more than 10 years due to realities of the automotive sensor business in comparison with the short life cycles of the electronics and semiconductor industry in general noted by, for example, Tse et al. (2016), Mönch et al. (2018) as well as Uzsoy et al. (2018) might limit the relevance of especially the life cycle cost thinking based on frequency of risks behind the construction if applied in the business environment with shorter life cycles. Similar limitation is related to the long lead times of multiple months present in the supply chains of the Client and natural for the semiconductors as noted by Christopher and Lee (2004, 390). Present are also the long supplier validation times noted in the testing of the model which increase the impact of many supply chain risks as the recovery time affecting customer deliveries is longer. Thus, the functionality of the construction could be different in the contexts with shorter lead times and validation times. In addition, the dynamics of the cost of sales impact could be different in, for example, B2C context as the supply shortages would lead to loss of customer demand more instantly than in the environment of Client company where design change of the customer is a long and expensive activity.

Furthermore, the high level of sophistication of automotive industry noted by Canbolat et al. (2008, 5151) was visible in the case as the tools such as FMEA as well as general idea of risk analysis were familiar to the company driven by the industry standards implemented due to the automotive customers. The applicability of tools in the contexts with less maturity and familiarity related to the risk analysis could be, thus, more limited.

7.5 Future research

In this final subchapter of the thesis, the future research opportunities are reviewed based on the theoretical contribution and limitations of the study. The review is further strengthening the link of the results of the thesis to the scientific knowledge.

Firstly, due to the short time span of the thesis project, it would be very interesting to revisit the supply chain risk management practices and the possible actions taken due to the risk analysis carried out by the Client company. This approach is similar to the recent advancements of the SCRM literature as Norrman and Wieland (2020) revisited the SCRM practices of Ericsson after 15 years of the classic study by Norrman and Jansson (2004) in one of the first longitudinal studies of the field.

Secondly, the thesis was only focusing on the first two steps of the supply chain risk management: risk identification and risk assessment (see e.g. Zsidisin et al. 2005, 3405; Manuj & Mentzer 2008a, 143; Fan & Stevenson 2018, 208). Thus, integration of the construction and the research design more deeply to the subsequent steps of risk mitigation and monitoring could support the holistic approach of SCRM in the construction even more profoundly.

Thirdly, it would be interesting to apply and test the construction in other industrial settings than in the mixture of semiconductor and automotive industries utilized in this study. Interesting context could be found from, for example, aviation and pharmaceutical industry with similar or higher level of sophistication or consumer electronics with shorter life cycles and less sophisticated industry standards. This research opportunity is supported by Lukka (2000, 7) who comments that the follow-up of implementation of the construction to other contexts should be managed by the future research.

Finally, the synthesis of the TCO and SCRM approaches with limited coverage in neither of the fields of literature would call for additional research efforts. This research opportunity is justified by the potential based on the prominent expectations by the researchers, by the low number of applications in the literature, as well as by the results of this thesis strengthening the connection of the two approaches.

REFERENCES

Adhitya, A. – Srinivasan, R. – Karimi, I. A. (2009) Supply chain risk identification using a HAZOP-based approach. *AIChE Journal*, Vol. 55 (6), 1447–1463.

Applequist, G. E. – Pekny, J. F. – Reklaitis, G. V. (2000) Risk and uncertainty in managing chemical manufacturing supply chains. *Computers & Chemical Engineering*, Vol. 24 (9), 2211–2222.

Bandaly, D. –Satir, A –Kahyaoglu, Y –Shanker, L. (2012) Supply chain risk management — I: Conceptualization, framework and planning process. *Risk Management*, Vol. 14 (4), 249–271.

Barney, J. – Wright, M. – Ketchen, D. J. (2001) The resource-based view of the firm: Ten years after 1991. *Journal of Management*, Vol. 27 (6), 625–641.

Berle, Ø – Norstad, I. – Asbjørnslett, B. E. (2013) Optimization, risk assessment and resilience in LNG transportation systems. *Supply Chain Management*, Vol. 18 (3), 253–264.

Blackhurst, J. V. – Scheibe, K. P. – Johnson, D. J. (2008) Supplier risk assessment and monitoring for the automotive industry. *International Journal of Physical Distribution & Logistics Management*, Vol. 38 (2), 143–165.

Bloomberg.com 7.4.2021 How Toyota Steered Clear of the Chip Shortage Mess. < https://www.bloomberg.com/news/articles/2021-04-07/how-toyota-s-supply-chain-helped-it-weather-the-chip-shortage>, retrieved 14.4.2021.

Bogataj, D. – Bogataj, M. (2007) Measuring the supply chain risk and vulnerability in frequency space. *International Journal of Production Economics*, Vol. 108 (1), 291–301.

Cachon, G. P. (2004) The allocation of inventory risk in a supply chain: Push, pull, and advance-purchase discount contracts. *Management Science*, Vol. 50 (2), 222–238.

Canbolat, Y. B. – Gupta, G. – Matera, S. – Chelst, K. (2008) Analysing risk in sourcing design and manufacture of components and sub-systems to emerging markets. *International Journal of Production Research*, Vol. 46 (18), 5145–5164.

Chopra, S. – Sodhi, M. S. (2004) Managing risk to avoid supply-chain breakdown. *MIT Sloan Management Review*, Vol. 46 (1), 53–87.

Christopher, M. – Lee, H. (2004) Mitigating supply chain risk through improved confidence. *International Journal of Physical Distribution & Logistics Management*, Vol. 34 (5), 388–396.

Cigolini, R. – Rossi, T. (2010) Managing operational risks along the oil supply chain. *Production Planning & Control*, Vol. 21 (5), 452–467.

Colicchia, C. – Strozzi, F. (2012) Supply chain risk management: A new methodology for a systematic literature review. *Supply Chain Management*, Vol. 17 (4), 403–418.

Cousins, P. D. – Lamming, R. C. – Bowen, F. (2004) The role of risk in environment-related supplier initiatives. *International Journal of Operations & Production Management*, Vol. 24 (6), 554–565.

Degraeve, Z. – Labro, E. – Roodhooft, F. (2004) Total cost of ownership purchasing of a service: The case of airline selection at Alcatel Bell. *European Journal of Operational Research*, Vol. 156 (1), 23–40.

Durowoju, A. O. – Kai Chan, H. – Wang, X. (2012) Entropy assessment of supply chain disruption. *Journal of Manufacturing Technology Management*, Vol. 23 (8), 998–1014.

Ellram, L. M. (1993a) A framework for total cost of ownership. *The International Journal of Logistics Management*, Vol. 4 (2), 49–60.

Ellram, L. M. (1993b) Total cost of ownership: Elements and implementation. International *Journal of Purchasing and Materials Management*, Vol. 29 (3), 2–11.

Ellram, L. M. (1994) A taxonomy of total cost of ownership models. *Journal of Business Logistics*, Vol. 15 (1), 171–191.

Ellram, L. M. (1995) Total cost of ownership. *International Journal of Physical Distribution & Logistics Management*, Vol. 25(8), 4–23.

Ellram, L. M. – Siferd, S. P. (1998) Total cost of ownership: A key concept in strategic cost management decisions. *Journal of Business Logistics*, Vol. 19(1), 55–84.

Eriksson, P. – Kovalainen, A. (2008) *Qualitative methods in business research*. SAGE, Los Angeles.

Fahimnia, B. – Tang, C. S. – Davarzani, H. – Sarkis, J. (2015) Quantitative models for managing supply chain risks: A review. *European Journal of Operational Research*, Vol. 247 (1), 1–15.

Fan, Y. – Stevenson, M. (2018) A review of supply chain risk management: Definition, theory, and research agenda. *International Journal of Physical Distribution & Logistics Management*, Vol. 48 (3), 205–230.

Ferrin, B. G. – Plank, R. E. (2002) Total cost of ownership models: An exploratory study. *The Journal of Supply Chain Management*, Vol. 38 (2), 18–29.

Franca, R. B. – Jones, E. C. – Richards, C. N. – Carlson, J. P. (2010) Multi-objective stochastic supply chain modeling to evaluate tradeoffs between profit and quality. *International Journal of Production Economics*, Vol. 127 (2), 292–299.

FT.com 26.3.2021 New Suez crisis: A global economy creaking under the strain. < https://www.ft.com/content/87cb4674-6db7-41cf-a82e-44b83eaa436c>, retrieved 30.3.2021.

Gardner, J. T. – Cooper, M. C. (2003) Strategic supply chain mapping approaches. *Journal of Business Logistics*, Vol. 24 (2), 37–64.

Gaudenzi, B. – Borghesi, A. (2006) Managing risks in the supply chain using the AHP method. *The International Journal of Logistics Management*, Vol. 17 (1), 114–136.

Ghadge, A. – Dani, S. – Ojha, R. – Caldwell, N. (2017) Using risk sharing contracts for supply chain risk mitigation: A buyer-supplier power and dependence perspective. *Computers & Industrial Engineering*, Vol. 103, 262–270.

Ghoshal, S. (1987) Global strategy: An organizing framework. *Strategic Management Journal*, Vol. 8 (5), 425–440.

Hajmohammad, S. – Vachon, S. (2016) Mitigation, avoidance, or acceptance? managing supplier sustainability risk. *The Journal of Supply Chain Management*, Vol. 52 (2), 48–65.

Harland, C. – Brenchley, R. – Walker, H. (2003) Risk in supply networks. *Journal of purchasing and supply management*, Vol. 9 (2), 51–62.

Hasan, R. – Moore, M. – Handfield, R. (2020) Addressing social issues in commodity markets: Using cost modeling as an enabler of public policy in the Bangladeshi apparel industry. *The Journal of Supply Chain Management*, Vol. 56 (4), 25–44.

Helferich, O. K. – Cook, R. L. (2002) *Securing the supply chain*. Council of Logistics Management, Oak Brook, IL.

Hendricks, K. B. – Singhal, V. R. (2003) The effect of supply chain glitches on shareholder wealth. *Journal of Operations Management*, Vol. 21 (5), 501–522.

Hendricks, K. B. – Singhal, V. R. (2005a) Association between supply chain glitches and operating performance. *Management Science*, Vol. 51 (5), 695–711.

Hendricks, K. B. – Singhal, V. R. (2005b) An empirical analysis of the effect of supply chain disruptions on Long-Run stock price performance and equity risk of the firm. *Production and Operations Management*, Vol. 14 (1), 35–52.

Ho, W. – Zheng, T. – Yildiz, H. – Talluri, S. (2015) Supply chain risk management: A literature review. *International Journal of Production Research*, Vol. 53 (16), 5031–5069.

Hoek, R., van (2020a) Research opportunities for a more resilient post-COVID-19 supply chain – closing the gap between research findings and industry practice. *International Journal of Operations & Production Management*, Vol. 40 (4), 341–355.

Hoek, R., van (2020b) Responding to COVID-19 Supply Chain Risks—Insights from Supply Chain Change Management, Total Cost of Ownership and Supplier Segmentation Theory. *Logistics*, Vol. 4 (23), 1–18.

Hou, J. – Zhao, X. (2020) Toward a supply chain risk identification and filtering framework using systems theory. *Asia Pacific Journal of Marketing and Logistics*, Vol. 33 (6), 1482–1497.

Ihrig, S. – Ishizaka, A. – Mohnen, A. (2017) Target setting for indirect processes: A new hybrid method for the continuous improvement management of indirect processes. *Production Planning & Control*, Vol. 28 (3), 220–231.

Ivanov, D. – Dolgui, A. (2020) Viability of intertwined supply networks: Extending the supply chain resilience angles towards survivability. A position paper motivated by COVID-19 outbreak. *International Journal of Production Research*, Vol. 58 (10), 2904–2915.

Jüttner, U. – Peck, H. – Christopher, M. (2003) Supply chain risk management: Outlining an agenda for future research. *International Journal of Logistics*, Vol. 6 (4), 197–210.

Kaplan, R. S. (1998) Innovation action research: Creating new management theory and practice. *Journal of Management Accounting Research*, Vol. 10, 89–118.

Kasanen, E. – Lukka, K. – Siitonen, A. (1993) The constructive approach in management accounting research. *Journal of Management Accounting Research*, Vol. 5, 243–264.

Kenyon, G. – Neureuther, B. D. (2012) An adaptive model for assessing supply chain risk. *Journal of Marketing Channels*, Vol. 19 (2), 156–170.

Khan, O. – Christopher, M. – Burnes, B. (2008) The impact of product design on supply chain risk: A case study. *International Journal of Physical Distribution & Logistics Management*, Vol. 38 (5), 412–432.

Khan, O. – Zsidisin, G. A. (2012) *Handbook for supply chain risk management case studies, effective practices, and emerging trends*. J. Ross Pub, Fort Lauderdale, FL.

Kleindorfer, P. R. – Saad, G. H. (2005) Managing disruption risks in supply chains. *Production and Operations Management*, Vol. 14 (1), 53–68.

Knemeyer, A. M. – Zinn, W. – Eroglu, C. (2009) Proactive planning for catastrophic events in supply chains. *Journal of Operations Management*, Vol. 27 (2), 141–153.

Kraljic, P. (1983) Purchasing must become supply management. *Harvard Business Review*, Vol. 61 (5), 109–117.

Kumar, S. K. – Tiwari, M. K. – Babiceanu, R. F. (2010) Minimisation of supply chain cost with embedded risk using computational intelligence approaches. *International Journal of Production Research*, Vol. 48 (13), 3717–3739.

Kwak, D. – Rodrigues, V. S. – Mason, R. – Pettit, S. – Beresford, A. (2018) Risk interaction identification in international supply chain logistics. *International Journal of Operations & Production Management*, Vol. 38 (2), 372–389.

Labro, E. – Tuomela, T. (2003) On bringing more action into management accounting research: Process considerations based on two constructive case studies. *The European Accounting Review*, Vol. 12 (3), 409–442.

Leat, P. – Revoredo-Giha, C. (2013) Risk and resilience in agri-food supply chains: The case of the ASDA PorkLink supply chain in Scotland. *Supply Chain Management*, Vol. 18 (2), 219–231.

Lindholm, A. (2008) A constructive study on creating core business relevant CREM strategy and performance measures. *Facilities*, Vol. 26 (7/8), 343–358.

Liu, Z. & Nagurney, A. (2011) Supply chain outsourcing under exchange rate risk and competition. *Omega*, Vol. 39 (5), 539–549.

Lorentz, H. – Hilmola, O. (2012) Confidence and supply chain disruptions. *Journal of Modelling in Management*, 7(3), 328–356.

Lukka, K. (2000) The Key Issues of Applying the Constructive Approach to Field Research. In Reponen, T. (ed.) (2000) *Management Expertise for the New Millennium*. In Commemoration of the 50th Anniversary of the Turku School of Economics and Business Administration. Publications of the Turku School of Economics and Business Administration, A-1:2000, 113–128.

Lukka, K. (2003) The Constructive Research Approach. In Ojala, L. – Hilmola, O. (ed.) (2003) *Case Study Research in Logistics*. Publications of the Turku School of Economics and Business Administration, B-1:2003, 83–101.

MacKenzie, C. A. – Barker, K. – Santos, J. R. (2014) Modeling a severe supply chain disruption and post-disaster decision making with application to the Japanese earthquake and tsunami. *IIE Transactions*, Vol. 46 (12), 1243–1260.

Manuj, I. – Mentzer, J. T. (2008a) Global supply chain risk management. *Journal of Business Logistics*, Vol. 29 (1), 133–155.

Manuj, I. – Mentzer, J. T. (2008b) Global supply chain risk management strategies. *International Journal of Physical Distribution & Logistics Management*, Vol. 38 (3), 192–223.

March, J. G. – Shapira, Z. (1987) Managerial perspectives on risk and risk taking. *Management Science*, Vol. 33 (11), 1404–1418.

Micheli, G. J. L. – Cagno, E. – Di Giulio, A. (2009) Reducing the total cost of supply through risk-efficiency-based supplier selection in the EPC industry. *Journal of Purchasing and Supply Management*, Vol. 15 (3), 166–177.

Mitchell, V. (1995) Organizational risk perception and reduction: A literature review. *British Journal of Management*, Vol. 6 (2), 115–133.

Mori, M. – Kobayashi, R. – Samejima, M. – Komoda, N. (2017) Risk-cost optimization for procurement planning in multi-tier supply chain by pareto local search with relaxed acceptance criterion. *European Journal of Operational Research*, Vol, 261 (1), 88–96.

Munoz, A. – Clements, M. D. (2008) Disruptions in information flow. A revenue costing supply chain dilemma. *Journal of Theoretical and Applied Electronic Commerce Research*, Vol. 3 (1), 30–40.

Mönch, L. – Uzsoy, R. – Fowler, J. W. (2018) A survey of semiconductor supply chain models part I: Semiconductor supply chains, strategic network design, and supply chain simulation. *International Journal of Production Research*, Vol. 56 (13), 4524–4545.

Neiger, D. – Rotaru, K. – Churilov, L. (2009) Supply chain risk identification with value-focused process engineering. *Journal of Operations Management*, Vol. 27 (2), 154–168.

Nooraie, S. V. – Parast, M. M. (2016) Mitigating supply chain disruptions through the assessment of trade-offs among risks, costs and investments in capabilities. *International Journal of Production Economics*, Vol. 171, 8–21.

Norrman, A. – Jansson, U. (2004) Ericsson's proactive supply chain risk management approach after a serious sub-supplier accident. *International Journal of Physical Distribution & Logistics Management*, Vol. 34 (5), 434–456.

Norrman, A. – Wieland, A. (2020) The development of supply chain risk management over time: Revisiting Ericsson. *International Journal of Physical Distribution & Logistics Management*, Vol. 50 (6), 641–666.

NYTimes.com 14.9.2021 BP Shortcuts Led to Gulf Oil Spill, Report Says. < https://www.nytimes.com/2011/09/15/science/earth/15spill.html>, extracted 9.10.2021.

Pattanayak, A. K. – Prakash, A. – Mohanty, R. P. (2019) Risk analysis of estimates for cost of quality in supply chain: A case study. *Production Planning & Control*, Vol. 30 (4), 299–314.

Pettit, T. J. – Fiksel, J. – Croxton, K. L. – Jackson, R. – Hellman, T. – Patel, S. – Crone, M. (2010) Ensuring supply chain resilience: Development of a conceptual framework. *Journal of Business Logistics*, Vol. 31 (1), 1–21.

Pettit, T. J. – Croxton, K. L. – Fiksel, J. (2013) Ensuring supply chain resilience: Development and implementation of an assessment tool. *Journal of Business Logistics*, Vol. 34 (1), 46–76.

Piirainen, K. A. – Gonzalez, R. A. (2013) Constructive synergy in design science research: A comparative analysis of design science research and the constructive research approach. *Liiketaloudellinen Aikakauskirja*, Vol. 62 (3–4), 206–234.

Plankey-Videla, N. (2012) Informed consent as process: Problematizing informed consent in organizational ethnographies. *Qualitative Sociology*, Vol. 35 (1), 1–21.

Prabhakar, V. J. – Sandborn, P. (2012) A part total cost of ownership model for long life cycle electronic systems. *International Journal of Computer Integrated Manufacturing*, Vol. 25 (4–5), 384–397.

Rao, S. – Goldsby, T. J. (2009) Supply chain risks: A review and typology. *The International Journal of Logistics Management*, Vol. 20 (1), 97–123.

Rautiainen, A. – Sippola, K. – Mättö, T. (2017) Perspectives on relevance: The relevance test in the constructive research approach. *Management Accounting Research*, Vol. 34, 19–29.

Rice, J. B. J. – Caniato, F. (2003) Building a secure and resilient supply network. *Supply Chain Management Review*, Vol. 7 (5), 22–30.

Ruiz-Torres, A. J. – Mahmoodi, F. – Zeng, A. Z. (2013) Supplier selection model with contingency planning for supplier failures. *Computers & Industrial Engineering*, Vol. 66 (2), 374–382.

Sanchez-Rodrigues, V. (2010) Evaluating the causes of uncertainty in logistics operations. *The International Journal of Logistics Management*, Vol. 21 (1), 45–64.

Sanders, D. R. – Manfredo, M. R. (2002) The role of value-at-risk in purchasing: An application to the foodservice industry. *The Journal of Supply Chain Management*, Vol. 38 (1), 38–45.

Sawik, T. (2015) On the fair optimization of cost and customer service level in a supply chain under disruption risks. *Omega*, Vol. 53, 58–66.

Silbermayr, L. – Minner, S. (2016) Dual sourcing under disruption risk and cost improvement through learning. *European Journal of Operational Research*, Vol. 250 (1), 226–238.

Simchi-Levi, D. – Schmidt, W. – Wei, Y. – Zhang, P. Y. – Combs, K. – Ge, Y. – Gusikhin, O. – Sanders, M. – Zhang, D. (2015) Identifying Risks and Mitigating Disruptions in the Automotive Supply Chain. *Interfaces (Providence)*, Vol. 45 (5), 375–390.

Sodhi, M. S. – Lee, S. (2007) An analysis of sources of risk in the consumer electronics industry. *The Journal of the Operational Research Society*, Vol. 58 (11), 1430–1439.

Sodhi, M. S. – Tang, C. S. (2009) Modeling supply-chain planning under demand uncertainty using stochastic programming: A survey motivated by asset–liability management. *International Journal of Production Economics*, Vol. 121 (2), 728–738.

Svensson, G. (2002) A conceptual framework of vulnerability in firms' inbound and outbound logistics flows. *International Journal of Physical Distribution & Logistics Management*, Vol. 32 (2), 110–134.

Tang, C. S. (2006) Perspectives in supply chain risk management. *International Journal of Production Economics*, Vol. 103 (2), 451–488.

Tang, C. – Tomlin, B. (2008) The power of flexibility for mitigating supply chain risks. *International Journal of Production Economics*, Vol. 116 (1), 12–27.

Tang, O. – Nurmaya Musa, S. (2011) Identifying risk issues and research advancements in supply chain risk management. *International Journal of Production Economics*, Vol. 133 (1), 25–34.

Tomlin, B. (2006) On the value of mitigation and contingency strategies for managing supply chain disruption risks. *Management Science*, Vol. 52 (5), 639–657.

TENK – Tutkimuseettinen neuvottelukunta (2012) *Hyvä tieteellinen käytäntö ja sen loukkausepäilyjen käsitteleminen Suomessa.* Tutkimuseettisen neuvottelukunnan ohje. <https://tenk.fi/fi/ohjeet-ja-aineistot/HTK-ohje-2012>, retrieved 12.7.2021.

Truett, R. (2001) Tire-related costs mount for ford. Automotive News 75, 45.

Tsai, C. (2008). On supply chain cash flow risks. *Decision Support Systems*, Vol. 44 (4), 1031–1042.

Tse, Y. K. – Zhang, M. – Akhtar, P. – Macbryde, J. (2016) Embracing supply chain agility: An investigation in the electronics industry. *Supply Chain Management: An International Journal*, Vol. 21 (1), 140–156.

Tummala, R. – Schoenherr, T. (2011) Assessing and managing risks using the supply chain risk management process (SCRMP). *Supply Chain Management*, Vol. 16 (6), 474–483.

Tuncel, G. – Alpan, G. (2010) Risk assessment and management for supply chain networks: A case study. *Computers in Industry*, Vol. 61 (3), 250–259.

Uzsoy, R. – Fowler, J. W. – Mönch, L. (2018) A survey of semiconductor supply chain models Part II: Demand planning, inventory management, and capacity planning. *International Journal of Production Research*, Vol. 56 (13), 4546–4564.

Vanany, I. – Zailani, S. – Pujawan, N. (2009) Supply chain risk management: Literature review and future research. *International Journal of Information Systems and Supply Chain Management*, Vol. 2 (1), 16–33.

Vilko, J. P. P. – Hallikas, J. M. (2012) Risk assessment in multimodal supply chains. *International Journal of Production Economics*, Vol. 140 (2), 586–595.

Wu, T. – Blackhurst, J. – Chidambaram, V. (2006) A model for inbound supply risk analysis. *Computers in Industry*, Vol. 57 (4), 350–365.

Wu, T. – Blackhurst, J. – O'grady, P. (2007). Methodology for supply chain disruption analysis. *International Journal of Production Research*, Vol. 45 (7), 1665–1682.

Xu, S. – Zhang, X. – Feng, L. –Yang, W. (2020) Disruption risks in supply chain management: A literature review based on bibliometric analysis. *International Journal of Production Research*, Vol. 58 (11), 3508–3526.

Yeung, H. W. (2007) From followers to market leaders: Asian electronics firms in the global economy. *Asia Pacific Viewpoint*, Vol. 48 (1), 1–25.

Zachariassen, F. – Stentoft Arlbjørn, J. (2011) Exploring a differentiated approach to total cost of ownership. *Industrial Management + Data Systems*, Vol. 111 (3), 448–469.

Zsidisin, G. A. – Panelli, A. – Upton, R. (2000) Purchasing organization involvement in risk assessments, contingency plans, and risk management: An exploratory study. *Supply Chain Management*, Vol. 5 (4), 187–198.

Zsidisin, G. A. – Ellram, L. M. (2001) Activities related to purchasing and supply management involvement in supplier alliances. *International Journal of Physical Distribution & Logistics Management*, Vol. 31 (9), 629–646.

Zsidisin, G. A. – Ellram, L. M. – Carter, J. R. – Cavinato, J. L. (2004) An analysis of supply risk assessment techniques. *International Journal of Physical Distribution & Logistics Management*, Vol. 34 (5), 397–413.

Zsidisin, G. A. – Melnyk, S. A. – Ragatz, G. L. (2005) An institutional theory perspective of business continuity planning for purchasing and supply management. *International Journal of Production Research*, Vol. 43 (16), 3401–3420.

APPENDICES

Appendix 1. Supply chain risk source classification of final construction

On normal black = From the supply chain risk categories by Blackhurst et al. (2008)
On bold blue = Added based on case 1
On bold black = Added based on testing in cases 2 & 3
On bold red = Deleted based on testing in cases 2 & 3
Some sources have been hidden or modified due to confidentiality reasons

Flow	Type	Examples
Material	Capacity / **Availability**	Capacity flexibility, cost of capacity, **allocation situations, raw material availability, machine breakages**
	Quality	Product complexity, value of product, **test yield, quality expectations, unethical activities, quality issue support, long lead time for quality issues to be noticed**
	Inventory	Obsolescence, holding cost, value of product, **too high inventory levels leading to quality risk and high inventory value, storing damage to material, tooling management, changes for materials**
	Logistics	Number of brokers, on-time-delivery, responsiveness, **gross trade transportation prices, transportation damages, deliveries blocked, long lead time**
	Security	Theft
	Manufacturing	**Process change, over-specifying, non-compliance with supplier standard process**
	Other (material)	
Information	Information systems	Integration, information sharing, robustness, **version control, traceability rules, complex IT system controls, IT capacity, coherence of specs in SC**
	Forecast	Inaccuracy, demand variation, lead time variance, **theoretical vs real lead time difference, production plan changes, long delivery times, overall complexity of matching supply and demand, errors in forecasts**
	Intellectual property	Ownerships, **IP leaks, IP dispute, design glitches**
	Security	IS system security, **cyber-attacks, leaks, systems locked**
	Management/ relationship	Visibility, communication channels, **professionalism, personal relationship,** **lack of competence in automotive requirements, SC experience, resources for SC control, expectations on supplier about will to tailor solution, low level of relationship, middlemen, size differences between SC parties leading to poor service**
	Other (Information)	
Finance	Supplier commercial	Price, single sources, contracts, exchange rate, **ownership changes, strategic focus,** **supplier financial strength, restructuring, size differences between SC parties leading to higher prices, EOLs on single sources, raw material price changes, declining tech non-profitable for supplier, market situation in industry, supplier interest in Client business**
	Customer commercial	Customer financial strength, number of customers, **ownership change, strategic focus,** **market changes, demand decreases, customer program delays**
	Other (finance)	
Other/ multiple flows	Disruptions/disasters	Labor disputes, natural disasters, political unrest, **factory fires, water supply**
	Dependence	**Product uniqueness, single sources, flexibility**
	Legal	Legislative actions, **new restrictions for allowed materials**
	Other (other/multiple flows)	

Appendix 2. Supply chain risk impact classification of final construction

On normal black = From the literature review
On bold blue = Added based on case 1
On bold black = Added based on testing in cases 2 & 3
On bold red = Deleted based on testing in cases 2 & 3

Head type	Sub type	Examples
Financial	Sales	Loss of market share
		Loss of sales
		Sales price decrease
		Loss of program(s)
	Costs	Penalties / Compensations
		Inventory markdowns
		Additional promotion
		Insurance costs
		Cost of expediting
		Purchase cost
		Cost of additional labor
		Investments
		Cost of re-allocating labor resources
		Costs of changing production location
		Costs of redesign
		Cashflow issues
		Legislative penalties
	Other	
Process performance	SC performance	Service level
		Process performance
		Capacity utilization
		Inventory performance
		Product performance
		Material shortage
	Time **Delay**	Delivery delays
		Time to market **delay**
		Project schedule **delay**
		Lead time **delay**
	Quality	**Yield**
		PPM
		Rate of errors
	Other	
Resources	Physical	Damage to equipment
		Damage to property
	Social	Reputation
		Customer relationship
		Health & Safety

		Culture
		Supplier relationship
		Limited pool of suppliers
	Psychological	Self-perception about company or project "Loss of morale"
		Paralysis of reaction
		Learning
	Information	Loss of data
		Accuracy of data
		Accessibility of data
		Damage to production software
	Environment	Emissions
		Lost resources
	Other	
Other	Other	

Appendix 3. Supply chain risk driver classification of final construction

On normal black = From the literature review
On bold blue = Added based on case 1
On bold black = Added based on testing in cases 2 & 3
On bold red = Deleted based on testing in cases 2 & 3

Head type	Sub type
Relationship & influence	Influence between SC entities
	Influence on external parties
	Size differences between SC parties
SC environment	Locations
	Industrial context
	Climate change
	Client processes
	Market context
Time	Recovery time
	Speed of detection
	Product / **tech** life cycle
	Lead time
SC complexity	Amount of tiers
	Amount of material items
	Number of countries
	Process standard
SC integration	Information systems
	Visibility
	Communication channels
Lack of confidence	
Amount of buffer **Flexibility**	Inventory
	Capacity
	Human resources
	Design flexibility
	Cash reserves
	Validated customers
	Potential customers
	Validated sources
	Potential sources (supplier pool)
Perception of risk	Risk awareness
	Risk culture
	Executive commitment
	Managerial competence

Appendix 4. Cost component list of final construction

Green highlight = Added as per testing
Red highlight = Deleted as per testing
Blue text = Linked to other cost component

Head type	Sub type	#	Cost components	Trigger (others can be identified as per scenario)
Financial	Sales	1	**Lost sales impact** = Profit of lost programs	> 12 months of gap in customer deliveries.
		2	**Delayed sales impact** = Capital cost of delayed sales + Penalty cost	Delay in customer deliveries.
			Cost of sales price decrease	
	Costs	3	**Cost of redesigning SC (new supplier)** = Validation labor cost + Travelling + Higher production cost + Validation materials + Investments + Increasing buffer inventory vs **Extra cost of waiting** = Lost sales + Delayed sales 1 & 2	Need to validate new supplier. Needed to be compared with waiting for rebound.
		4	**Cost of re-allocating volumes** = Unit price change + investments vs **Cost of redesigning SC (new supplier)** = Cost of redesigning (3) vs **Cost of waiting** = Lost sales + Delayed sales 1 & 2	Need to change volumes to another validated supplier. Needed to be compared with new supplier validation and waiting for rebound.
			Procurement:	
		5	Increased purchase price	Supplier increases unit price or service fees
		6	Cost of expediting	Hot lot fees are triggered by supplier.
		7	Cost of cancelling orders	Orders/forecast must be cancelled, and supplier does not accept cancellation without penalty.
		8	Investments	Investments needed
			Marketing:	
			Additional marketing cost	
			Labor cost:	
		9	Extra working	Labor cost created by the risk scenario and used to ensure continuity.
		10	Travelling	Travelling needed to sort a case.
			Increased amount of transactions	
			Overtime working	
			Higher cost of recruiting	
			Relationship management:	
		11	Higher cost of business relationship ~~(guarantees or assurances)~~ = Extra working (9)	Extra labor cost of relationship management
			Logistics:	
		12	Cost of delivery damage = Cost of delivery delays (20)	Material is damaged in delivery.
		13	Cost of increased deliveries	More deliveries needed
		14	Increased freight cost	Freight cost increases
		15	Cost of premium freight	Premium freight fees are triggered by logistics partner
			Increased warehousing cost	

			Finance:	
		16	Regulatory fines	Regulatory fines are collected by governmental institution.
			Insurance premium cost Cost of currency fluctuations Higher cost of capital	
	Share-holder value		Decreasing share price Increasing cost of capital Cost of investor relations	
Process perfor-mance	SC per-formance	17	**Cost of working capital performance loss** = (Change of inventory EUR + Change of receivables EUR - Change of payables EUR) * Cost of capital	E.g. Payment times to supplier shortened or lead time is extended.
		18	**Cost of increased inventory** = Cost of working capital performance loss (17) + Markdown costs	More inventory is carried e.g. due to buffer building.
		Sup-port	**Change of inventory (buffer)** = MAX(Business recovery time * rate of sales - inventory buffer; Detection time * rate of production) / 2	
			Cost of decreased inventory Cost of lost product performance	
	Delays	19	**Cost of delayed time to market** = Lost sales + Delayed sales (1 & 2)	Product launch is delayed (validation risk event)
		20	**Cost of delivery delays** = Lost sales + Delayed sales (1 & 2)	Delay of deliveries.
		21	**Cost of project delay** = Extra working (9)	Project is delayed.
		22	**Cost of longer lead time** = Cost of working capital performance loss (17)	Lead time is extended when e.g. supplier is changed.
	Quality	23	**Cost of yield loss** = Additional production cost + additional purchases + Cost of delivery delays (20)	Testing yield is lower than expected for a certain time due to root cause in supply chain or supplier operations. Also cases of expiry / damage in warehousing by Client.
		24	**Cost of bad quality (PPM risk realized)** = Warranty cost + Cost of ordering more/Cost of scrapping/Cost of reworking + Sorting work and other labor (9) + Cost of delivery delays (20)	Quality issue due to root cause in supply chain or supplier operations is detected at customer.
Resources	Physical	25	**Cost of physical asset loss** = Markdown of book values	E.g. machine is written off.
	Social		Cost of reputation loss	
	Psycho-logical		-	
	Infor-mation	26	**Cost of IT flow disruption** = Cost of delivery delays (20)	E.g. cyber-attack prevents deliveries.
	Environ-ment	27	**Cost of environmental impact** = Regulatory fines (16) + Cleanup costs	Environmental incident (e.g. spillage)