Supply Chain Risk Assessment: systematic review and research directions

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Abstract. This article explores perspectives on risk assessment in the supply chain, identifying tools most used in the literature on risk assessment in the supply chain Two phases were used as a methodological procedure: 1- systematic review of the literature for theoretical survey of articles focusing on the phase risk assessment; and 2- identification and quantification of the tools used for risk assessment. From this, there was a significant number of theoretical reviews on SCRM, however, knowledge about risk assessment is still diffuse, being considered the most critical and complex phase in risk management. The main tools identified were simulation and Bayesian networks to define risk probability and probability and impact matrices and AHP to identify the most critical risks.

Keywords: Risks, Supply Chain Risk Management, risk assessment, general review.

1 Introduction

Within the context of Supply Chain Risk Management (SCRM), companies and professionals are attentive to risk management due to an increasing occurrence of risk events and their impact (Sodhi; Son; Tang, 2012; Kumar; Himes; Kritzer, 2014; Fazli; Mavi; Vosooghidizaji, 2015). The complexity of supply chains (SC) has a direct influence on risks (Punniyamoorthy; Thamaraiselvan; Manikandan, 2013) as the chain's companies share not only rewards but also risks with each other.

In addition to the complexity inherent of the SC, vulnerability increases because of environmental, socio political and economic events. Thun and Hoenig (2011) and Sodhi, Son and Tang (2012) warn that events such as the September 11 attacks, Hurricane Katrina in 2005 and the tsunami in Japan in 2011 showed that global supply chains are exposed to unexpected situations and, for this reason, should plan how to react face such occurrences. Moreover, Yang and Yang (2010) highlight that vulnerability increases due to a greater use of practices such as outsourcing and e-business, and the adoption of these practices raises the likelihood of chain disruptions.

Broadly speaking, risk is understood as a relationship between severity/impact and frequency/likelihood of occurrence (Ritchie; Brindley, 2007; Trkman; Mccormack, 2009; Tang; Musa, 2011; Wieland, 2013; Kumar; Himes; Kritzer, 2014). Based on the assessment of these aspects, managers can decide on risk mitigation strategies. In this

way, the SC can plan before disruptions in the process that would pose negative effects on the whole chain (ASBJORNSLETT, 2009).

Khan, Christopher and Burnes (2008), Rao and Goldsby (2009), Thun and Hoenig (2011) and Sun, Matsui, and Yin (2012) point that the interest in SCRM is evidenced by research efforts, especially regarding theoretical reviews on the theme, aimed at organizing knowledge and guide further investigations. Examples of theoretical reviews on SCRM are Vanany, Zailani and Pujawan (2009), Tang and Musa (2011), Singhal, Agarwal and Mittal (2011), Sodhi, Son and Tang (2012), Colicchia and Strozzi (2012), Ghadge, Dani and Kalawsky (2012), Olson and Wu (2010), Pfohl, Kohler and Thomas (2010), Ceryno *et al*. (2013), Fahimnia *et al*. (2015), Ho *et al.* (2015), Qazi, Quigley and Dickson (2015); Fan and Stevenson (2018), Bier *et al* (2020), and Xu *et al* (2020).

Though acknowledging the importance of SCRM and the existence of several theoretical review studies about SCRM, there is a scarcity of publications focused on discussing risk assessment. According to Kumar, Himes and Kritzer (2014), risk assessment requires a special attention in SCRM because it is through risk assessment that risk criticality is made known, and the risk treatment priority is defined. Thus, the assessment process is an important instrument to estimate the consequences of a risk and prioritize strategies towards mitigating risks.

Thus, even though risk assessment is considered the most critical and complex phase in supply chain risk management, knowledge about the techniques and tools already tested for risk assessment is very diffuse, and no research was undertaken to compile the applications and results already developed to evaluate the risks in the supply chain. This research fills that gap by outlining a general profile of how risk assessment has been delineated by risk management models in the supply chain. Moreover, this work helps to guide future research, as it points to what has already been tested and which combination remains a gap to be filled in the SCRM field of expertise.

The key questions in this research include: What is the nature of approaches developed in SC risk assessment? What are the tools for SC risk assessment? Additionally, this article seeks to explore perspectives to support the theoretical development in SC risk management by creating a historical chronogram of the progress made, identifying approaches, and tools for SC risk management and assessment, and attempting to detect behavior patterns established in the literature.

The objectives of this article comprehend: (a) survey of the literature about supply chain risk assessment, (b) mapping of approaches for risk assessment and (c) identification of tools and techniques used in risk assessment. From these objectives, research questions include RQ1: What is the current state (state of the art) of SC risk assessment? RQ2: What were the techniques and tools used in risk assessment?

2 Research method: a systematic literature review

The present research is supported by a systematic review of the literature on risk assessment in supply chains (SC). This type of research can provide a useful approach to identifying themes and selecting keywords to make the first choice regarding the most relevant contributions in the field (COLICCHIA; STROZZI, 2012).

This study was carried in 2021. The theoretical survey considered articles published between 2000 and 2020. The research began with the definition of bases and keywords. It was defined that the articles would be searched in two search bases: Scopus and Web of Science, with the keywords "supply chain risk management". This resulted in the collection of 655 articles in both databases (Figure 1).

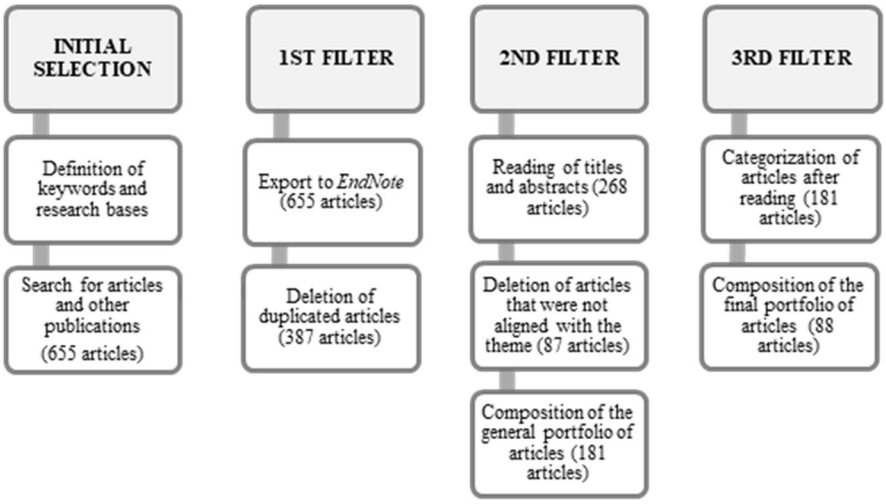

Fig. 1. Selection of the portfolio of analyzed articles.

Data collection on the bases was followed by the filtering of articles with the aim of obtaining only those considered relevant for the theme. The first filter consisted of disregarding duplicated articles, since different databases and multiple keyword combinations were used. To assist in this process, the EndNote TM basic platform was used, which excluded 387 articles with repeated titles. Thus, 268 articles remained. Subsequently, titles and abstracts were read to select only articles that addressed SC risk assessment. Such reading excluded other 87 articles, resulting in 181 articles in the general portfolio, which were then fully read. With the reading of the 181 articles, it was possible to identify the following categories: 1- articles that performed only the risk identification stage; 2 – articles that moved further to risk assessment, including or no other stages of the risk management process (risk mitigation and monitoring); 3- articles that discussed general aspects about SCRM, including resilience, risk factors and theoretical review of SCRM. Since the focus of this theoretical review is the risk assessment phase, other 93 articles were excluded, which resulted in 88 articles that presented SC risk assessment models and composed the final portfolio with which the analyses herein presented were carried out.

3 Analysis and discussion of results

3.1 Supply chain risk assessment

In general, SCRM models, according to Cohen and Kunreuther (2007), Giannakis and Louis (2011) and Tummala and Schoenherr (2011), included four generic stages: 1 – risk identification; 2 – risk assessment; 3 – proposition of strategies to accept, transfer, reduce or eliminate risks; and, finally, 4 – impact monitoring.

Among those stages, the risk identification phase is the first step towards risk management process (Pfohl *et al*, 2011; Ho *et al*., 2015). The identification of risks aims to gather relevant information (Kern *et al*., 2012). However, the risk assessment phase is regarded as the most critical and complex one in risk management and requires special attention as it can involve different tools and methods to assess the dimension of the risk (Kumar; Himes; Kritzer, 2014). Aloini *et al.* (2012) highlight that risk assessment is the most challenging assessment for researchers.

According to those characteristics, it was observed that all risk assessment models start with risk identification; however, not all of them propose risk assessment typologies. Thus, there is an effort greatly concentrated on the discussion and proposition of risk assessment proposals, which necessarily goes through risk identification, without necessarily involving a risk classification proposal. This evidences the statements by Aloini *et al*. (2012) about research efforts and the criticality of the risk assessment phase in SC risk management.

Despite big research efforts in the risk assessment phase, it is worth stressing that such a phase is complex and critical (Kumar; Himes; Kritzer, 2014), as it can be performed with the aid of different techniques and tools and through different approaches to assess the risks as thoroughly as possible.

The purpose of risk assessment is to subsidize decisions on risk treatment. Purdy (2010) highlights that risk analysis has as objective the understanding of each risk, its consequences, and the likelihood of its consequences, whereas risk assessment involves the making of a decision on risk level and priority according to criteria established by the company.

Risk assessment processes information on the likelihood of occurrence of risks along with the measuring of impacts related to them. The criticality of risk assessment lies in the quantification of these two aspects, because risk is a parameter with a high degree of uncertainty and intangibility, therefore.

Therefore, risk assessment is the most complex step in risk management (Cao and Song 2016), since it may involve the use of different tools, including their combined use, especially for the calculation of probability of occurrence, which may be a fully qualitative or quantitative measure. That's why Badurdeen *et al.* (2014) and Aqlan and Lam (2015) pointed out three categories of tools for risk assessment: 1- Purely qualitative, such as failure mode and effect analysis (FMEA); impact and probability matrices are widely used for chain risk analysis in the absence or limitation of historical data; 2- Purely quantitative tools are mainly used for risk analysis, high lighting simulation, which is an effective tool to visualize the risks and is useful to deal with the stochastic nature and the uncertainties of risk in the supply chains, simulation techniques that are

commonly used include discrete event simulation (DES), dynamic systems (DS), MCS (Monte Carlo Simulation), and Petri Nets; and finally, 3- Hybrid tools combine qualitative and quantitative approaches because of the uncertainty of risks in supply chains. In this last category the most common tools used for qualitative-quantitative risk modeling are Analytic Hierarchy Process (AHP), Analytic Network Process (ANP) and fuzzy logic.

Understanding the scenario for the application of each nature of these tools helps managers to make more appropriate choices for the application of risk management models in supply chains, based on the characteristics and availability of available data on risks. In addition, identifying the effort of the literature in the application of these different tools helps in directing works on the subject, since the risk assessment phase is one of the most complex phases of the SCRM models and can point out ways to be explored in future works in this field. thematic.

To identify tools used in risk assessment, a survey was conducted in the portfolio of articles herein analyzed, whose result is displayed in Table 1. To outline a chronological profile of articles addressing supply chain risk assessment, this study first analyzed the evolution of the theme from 2000 to 2020.

Table 1. Summary of tools used in risk assessment in articles from 2000 to 2020

RISK ASSESSMENT TOOLS	WORKS
SIMULATION	Deleris; Erhun (2005); Yang; Wu (2008); Schmitt; Singh (2009); Manuj, Mentzer, Bowers (2008); Jin; Zhuang; Liu (2010); Khilwani, Tiwari; Sabuncuoglu (2011); Schmitt; Singh (2012); Yang, Tang; Yan (2012); Vilko; Hallikas (2012); Durowoju, Chan;Wang (2012); Feng (2012); Gallo *et al* (2012); Berle, Norstad;Asbjørnslett (2013); Ghadge *et al* (2013); Guertler; Spinler (2015)
SIMULATION /DEA	Wu; Olson (2008)
SIMULATION / FMEA	Tuncel; Alpan (2010)
SIMULATION / PARETO	Kumar; Nigmatullin (2011)
SIMULATION / DYNAMIC PROGRAMMING	Cheng; Duran (2004)
SIMULATION /FMEA/FMECA	Kumar, Boice; Shepherd (2013)
FUZZY	Wen; Xi (2007); Behret, Oztaysi; Kahraman (2011)
FUZZY /ELECTRETRI-C	Govindan; Jepsen (2016)
FUZZY / TOPSIS	Chatterjee; Kar (2013)
FUZZY / Faults Tree Analysis	Li; Yu (2010)
AHP	Gaudenzi; Borghesi (2006); Wu, Backhurst; Chidambaram (2006); Funo *et al* (2011); Xia; Chen (2011); Lee; Ulferts (2011); Prakash *et al* (2014)
AHP /FUZZY	Ganguly;Guin (2013); Sofyalioglu; Kartal (2012); Samvedi, Jain; Chan (2013); Radivojević; Gajović (2014)
AHP / FMEA	Chen;Wu (2013)
BAYESIAN NETWORKS	McCormack (2007); Han; Chen (2007); Lockamy; McCormack (2010); Lockamy; McCormack (2012); Lockamy (2014); Amundson *et al* (2014); Badurdeen *et al.* (2014);

	Cao; Bryceson (2019); Daultani *et al* (2019); Qazi *et al*. (2020);
BAYESIAN NETWORKS / FUZZY	Pai *et al* (2003)
BAYESIAN NETWORKS / SIMULATION	Garvey et al (2015); Zheng and Zhang (2020)
BAYESIAN NETWORKS / SIMULATION/ FMEA	Nepal, Yadav (2015)
FMEA	Bradley (2014); Lavastre, Gunasekaran e Spalanzani (2014)
FMECA / FAULTS TREE ANALYSIS	Kumar; Havey (2013)
FMECA/PARETO	Pradhan; Routroy (2014)
LIKELIHOOD AND IMPACT MATRIX	Hallikas *et al* (2004); Ritchie; Brindley (2007); Blackhurst, Scheibe; Johnson (2008); Thun; Hoenig (2011); Blome; Schoenherr (2011); Tummala; Schoenherr (2011); Ouabouch; Amri (2013); Kumar, Himes; Kritzer (2014)
Faults Tree Analysis / Events Tree Analysis	Lin; Zhou (2011); Sherwin et al (2016); Mogre *et al* (2016)
Faults Tree Analysis/Events Tree Analysis /FUZZY	Aqlam; Lam (2015)
Faults Tree Analysis /Events Tree Analysis/ HAZOP	Cigolini; Rossi (2010)
Faults Tree Analysis/ FUZZY	Li; Yu (2010)
Faults Tree Analysis/ FMECA	Kumar; Havey (2013)
INTERPRETIVE STRUCTURAL MODELLING	Faisal; Shankar (2007); Pfohl, Gallus; Thomas (2011); Diabat, Govindan; Panicker (2012); Hachicha; Elmsalmi (2014)
DEA	Zeng, Rogers (2011)
DEA / SIMULATION	Olson; Wu (2011)
ANP	Xia; Chen (2011); Cao; Song (2016)
ANP/ DEMATEL	Fazli *et al* (2015);); Muchfirodin *et al* (2015); Ramesh *et al* (2019)

Table 1 shows that the main tool used in risk assessment is simulation (19%). It is also observed that the simulation is used in combination with other tools in 28% of the studies surveyed. In studies that use simulation, it is useful to calculate the probability of risk, an important component in risk assessment. In this case, the simulation becomes an important tool in the absence of historical data that allow the easy calculation of the risk probability. Secondly, Bayesian networks are the most used tool (13%), and when the combined use with other tools is considered, 18% of the studies used Bayesian networks as a tool for risk assessment. In these studies, there is a concern with risk dependence. Then there is the still important use of probability and impact matrices (10%), which demonstrates that this tool, even with simplicity of application, still has a strong role in risk assessment. Fourthly, the use of AHP (8%) and in a combined manner is observed in 14% of the studies analyzed, which indicates the importance of prioritizing risks in the risk assessment phase. In addition to these tools, attention is drawn to the use of Faults Tree Analysis (9%), fuzzy logic (6%), ANP (5%). The other tools had applications around 1% of the analyzed studies, which shows ample space for future research to better test the application of these tools.

These analyzes demonstrate that in the scope of risk assessment, the complexity of measuring the probability and impact of risks, as well as the availability of data on these parameters, allow the varied use of tools, and even the combined use with several tools for this purpose. These observations indicate that the use of tools such as simulation and fuzzy logic is largely related to the lack of historical data recorded on risks by companies. The use of tools such as AHP and impact and probability matrices demonstrate that these parameters can be subjective based on expert beliefs, given the absence of historical data on risks. This indicates that the application of risk management models in the supply chain by companies is still incipient, a fact that needs to be observed, not only to have data that allow the use of tools with the probability and impact of the measured risk, but also to promote the use of these management models that can generate benefits and positive results for the companies they employ.

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