Automotive Supply Chain Risk Management: State-of-the-Art Review

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Abstract

Purpose - The automotive industry plays an important role in the global economy. The goal of this research is threefold: 1. to provide a summary and a classification for the underlying supply chain risk resources in the automotive industry by considering the characteristics of automotive supply chains; 2. to provide an overview of the current research on automotive supply chain risk management (ASCRM); and to discuss several areas of future research on ASCRM.

Design/methodology/approach - We conduct the research review based on the unique features of automotive supply chains. A systematic literature review of 130 articles (published 2000- Sept. 2018) is conducted to analyze and synthesize findings to provide an overview of the current research on ASCRM, with an emphasis on the quantitative methods and mathematical models currently used.

Findings - The main findings of this research include: (1) Research on ASCRM has been increasing in recent years. (2) The main mathematical models include optimization models, such as mixed integer/nonlinear programing, multi-objective optimization, newsvendor models, and game theory; tools such as value at risk and conditional value at risk have rarely been used. (3) The automotive industry recognizes the importance of ASCRM and expends considerable effort on its investigation but academic research is thus far insufficient. Six future research directions are presented.

Practical implications - Managers are encouraged to adopt qualitative or quantitative approaches to ASCRM. There are many risk mitigation strategies, such as build resilient SC, increase SC transparency, supply chain coordination etc. and some practical tools such as Risk-Exposure Model, MCDM and FMEA, but there is a lack of real-time risk alarm systems and tools for supply chain resilience.

Originality/value - The paper is the first literature review to focus on ASCRM research. The sources of automotive supply chain risks are summarized and classified. The quantitative methods and mathematical models on automotive supply chain risk management are analyzed. Six areas of future research on ASCRM are identified. The work lays a foundation for further research in ASCRM.
Keywords Supply chain risk management, Automotive, Risk identification, Risk analysis, Review

Paper type Literature review

1. Introduction

The automotive industry is one of the world's most important economic sectors in terms of revenue and employment. According to automotive industry statistical data from OICA (2016), almost 95 million cars and commercial vehicles were produced in the world in 2016, with over 8 million direct jobs in the assembly and manufacture of components, representing > 5% of the world’s industrial employment, and almost five times more indirect jobs (González-Benito et al., 2013).

The automotive supply chain is complex owing to the large number of parts assembled into an automobile, the multiple layers of suppliers to supply those parts, and the coordination of materials, information, and finance flows across the supply chain. Over the past decades, automotive supply chains in the world have been stricken and disrupted repeatedly by natural and human-made disasters, such as earthquakes, tsunamis, hurricanes, strikes, economic crises, SARS, plant fires and explosions, terrorist attacks, and other disruptive events. Such supply chain disruptions can detrimentally impact a firm’s short-term performance. At the same time, the automotive business has become increasingly more complex as globalization has become an industry norm. Other new practices, such as just-in-time (JIT) delivery, lean manufacturing or lean production (Mo and Cook 2018; Nakashima and Sornmanapong, 2013), and supplier consolidation, are also employed. As a result, automotive supply chains have become increasingly more vulnerable to various risks. Thus, supply chain risk management (SCRM) plays a critical role in the automotive industry.

The automotive industry is well known for its efforts to improve its supply chains based on its demanding business environment and to protect against the harmful effects of supply chain disruptions to its companies through SCRM. However, research work and publications have not caught up with the pace required by the industry, though there are many research papers that directly address automotive SCRM (ASCRM). We searched related articles on ASCRM, mainly from Scopus, SCI, SSCI, and ABI/INFORM, and some related materials available on the Internet. A search using “automotive supply chain/logistics risk management” as the keywords generated 129 document results from the Scopus database by Nov.2019. Our review is not limited to these articles. Figure 1
shows the chronological distribution of papers and a general increasing trend from 2008. However, there is no review literature devoted to ASCRM.

To lay a foundation for further research in the area, this study provides a review of the general research work on supply chain risk identification and management for the automotive supply chain where the literature is available and seeks the answers to two key questions: (1) What are the underlying supply chain risk resources in the automotive industry? (2) How have they been addressed in the current literature, with a focus on quantitative methods and mathematic models? This review is based on 149 papers and websites addressing SCRM for the automotive industry and other related industries.

**Figure 1.** Chronological distribution of papers from 2000 to Nov. 2019 from the Scopus database.

SCRM is "the process of risk mitigation achieved through collaboration, coordination, and application of risk management tools among the partners, to ensure continuity coupled with long-term profitability of the supply chain" (Faisal et al., 2007). It should be noted that risk cannot be completely eliminated from supply chains, but strategies can be developed to manage these risks if the dynamics between the variables related to risks in a supply chain are understood. The main objective of SCRM is to maximize the expected profit or minimize the expected loss when a supply chain disruption occurs (Tang, 2006). Risk management has become an essential tool in addressing risk issues in supply chain management.

In general, the SCRM process consists of four components (Fan and Stevenson 2018, Hallikas et al., 2004): risk identification, risk assessment, risk treatment or management decisions and implementation, and risk monitoring. In line with these classifications, this review presents a
summary and analysis with emphasis on the first three aspects of ASCRM and provides quantitative models and future research directions as well.

The rest of this literature review is organized into six sections. Section 2 discusses the characteristics of the automotive supply chain. Section 3 studies automotive supply chain risk identification and classification. Section 4 examines the methodologies of supply chain risk assessment. Section 5 reviews the theoretical models, the qualitative approaches, and practical tools for risk management. Some future research directions and conclusions are discussed in Section 6.

2. Automotive Supply Chains and Literature Distribution on Automotive Supply Chain Risks

The automotive supply chain includes raw material manufacturers, multilayer part suppliers, car manufacturers, dealers, and customers. There are about 20,000 parts in a car, and if even only one of these parts is not available, then the vehicle cannot be shipped. Typically, there are three to five or more layers in an automotive supply chain, which comprises thousands of suppliers. A typical automotive OEM has up to 10 tiers between itself and its raw materials. For example, Ford has ∼1,400 Tier-1 suppliers across 4,400 manufacturing sites and hundreds of thousands of lower tier suppliers (Simchi-Levi et al., 2015). Figure 2 displays the schematic automotive supply chain (Timothy, 2011).
Figure 2. Automotive supply chain (Timothy, 2011).

The automotive industry is characterized by low margins, high volumes, high costs, global supply chains, and multilayer suppliers (Simchi-Levi, 2015; Singhal, et al. 2011). Automotive supply chains are deep and broad. For decades, the automotive industry has employed different ways to cut costs for gaining competitive advantage. These practices result in low inventories, additional dependence on suppliers, added network complexity, and increased supply chain risks (Thun and Hoenig, 2011; Nakashima and Sornmanapong, 2013).

The automotive supply chain risks considered here include different risks and uncertainties that come from sourcing, supply, production, storage, logistics, and distribution in the automotive supply chain.

3. Automotive Supply Chain Risk Identification and Classification

Risk identification is the first step and a subjective component within the SCRM process. To reduce supply chain risks, firms should understand the universe of risk categories as well as the events and conditions that drive them. We analyzed the resources of supply chain risks existing in the automotive industry, and we classified the risks into the 10 categories shown in the fishbone diagram in Figure 3. Table 2 illustrates the automotive industry risk profile, risk events, and the references.

Figure 3. Automotive supply chain risk fishbone diagram.
4. Automotive Supply Chain Risk Assessment and Measures

Once risks are identified, their impacts and probabilities must be assessed. Risk assessment involves “a set of logical, systemic, and well-defined activities that provide the decision makers with a sound identification, measurement, quantification, and evaluation of the risk associated with certain natural phenomena or man activities” (Haines, 2004). In this section, the models and methods used in the literature for assessing the automotive supply chain risk are presented in Appendix 1.

4.1 Probability Impact Matrix

The international engineering standard ISO14971 defines and assesses a risk R as the product of probability and the harm of an event \( e \): \( R = P_e S_e \), where \( S_e \) and \( P_e \) refer to the severity and probability of \( e \), respectively (Heckmann et al., 2015; ISO 14971:2007). Supply chain risk assessment aims to estimate the risk probability of occurrences and their adverse effect on the entire supply chain. In practice, the exact quantification of these values is often difficult because a precise assessment of the probability of occurrence and its effect is hardly possible; however, a qualitative method is advisable to evaluate the identified risk. The probability impact matrix is a qualitative risk assessing tool that has two dimensions: “probability” (from low to high) and “impact” (from weak to grave) based on a Likert scale. Through their survey in India, Sharma and Bhat (2014c) concluded that a likelihood/impact matrix is a widely used method of risk assessment in the automotive industry. Based on probability and impact of a risk, Fan and Stevenson (2018) provided a matrix of risk treatment strategies (show as Figure 4.) to guide managers how to select appropriate risk treatment actions.

![Probability Impact Matrix](image)

**Figure 4.** Matrix of risk treatment strategies based on probability and impact
(Source: Fan and Stevenson, 2018)
4.2 Fuzzy Assessment Method

Ghadimi et al. (2012) developed a weighted fuzzy assessment method for product sustainability assessment. A case study of an automotive component was conducted to illustrate the efficiency of the developed method. The results show how a simple replacement in the product material can lead a manufacturer toward producing more sustainable products and achieving the ultimate goal of sustainable manufacturing. Zarbakhshnia et al. (2018) also developed a multiple attribute decision making (MADM) model to rank and select sustainable third-party reverse logistics providers. The evaluation criteria was weighted using fuzzy weight assessment ratio analysis. The model was applied to a case study from automotive industry.

Zimmer et al. (2017) developed a fuzzy analytical hierarchy process to estimate and assess social risks along global supply chains. Their model was applied to a case study of a German premium car manufacturer and showed a great benefit for practitioners in purchasing functions of focal companies. Bello et al. (2018); Salehi Heidari et al. (2018) also used a Fuzzy –AHP (Analytic Hierarchy Process) model to perform risk assessment in automotive industry.

Vujović et al. (2017) applied fuzzy logic to classify risk factors in production supply chains with uncertain data from the automotive industry. Palanisamy and Zubar (2013), Datta et al. (2013), and Diabat et al. (2013) also utilized fuzzy logic for their ASCRM research.

For production supply chain economic and social sustainability, Đurić et al. (2019) developed a new fuzzy risk management model, which provided an easy and simple way to determine risk level from the automotive industry SC and proposed appropriate management initiatives for reducing or eliminating risk factor (RF) influence.

4.3 Mean–Variance Analysis

Mean–variance analysis introduced by Markowitz (1959) has been a standard tool for risk management. It tries to achieve a balance between the expected return and the specific risk measured by variance (Wu et al., 2010). Talluri et al. (2010) applied Markowitz’s model to manufacturer cooperation in supplier development under risk. They presented a set of optimization models that address supplier development undertaken by manufacturing firms to improve their suppliers’ capabilities and performance. The objective function is to minimize the risk of manufacturer’s investments to suppliers. Zhang and Zhu (2012) extended Talluri’s manufacturer cooperation model to the automotive industry where the return is nonlinear. Many automotive OEMs have implemented
supplier development programs to assist suppliers. When cooperating, firms share resources, benefits, as well as cost and risk.

However, some other traditional quantitative risk assessment tools, such as value at risk and conditional value at risk, have rarely been applied to the automotive supply chain.

4.4 Bayesian Networks

A Bayesian network is a probabilistic graphical model that represents a set of random variables and their conditional dependencies via a directed acyclic graph. Lockamy and McCormack (2012) and Lockamy (2014) used Bayesian networks to assess supply disaster risks in the automotive industry. The empirical data of design/methodology/approach are from 15 casting suppliers to a major US automotive company. They found that Bayesian networks can be used to develop supplier risk profiles, which can assist managers in making decisions regarding current and prospective suppliers. Abolghasemi et al. (2015) proposed a Bayesian method based on supply chain operations reference (SCOR) metrics. The method has the ability to manage supply chain risks and to improve supply chain performance. It was applied to one of the biggest automotive companies in Iran.

4.5 Other Risk Assessment Methods

Schöggl et al. (2016) provided a conceptual framework and an aggregation method for supply chain sustainability assessment by means of quantitative and qualitative indicators. Their results are based on a literature review of sustainability assessment in supply chains as well as on focus group workshops with experts from the European automotive and electronics industry. Their paper contributes to the theory and practice of sustainability assessment in supply chains. Xu et al. (2019) developed a framework to assess the supply chain sustainability risk considering the triple bottom line, or, operational risk, social risk, and environmental risk to form an aggregate metric. The case study of broad-structure automotive industry supply chain is used to demonstrate the application of the developed framework. Methods for assessing risk are also addressed in supplier evaluation and selection (Cagnin et al., 2016; Canbolat et al., 2008; Kull and Talluri, 2008).

Sharma and Bhat (2014c) also investigated the tools and techniques used in supply chain risk assessment practices by Indian automobile companies. Marasova et al. (2017) applied heuristics to risk assessment within the automotive industry supply chain.

A summary of the risk assessment and management methodology reviewed in this paper is given in Table 3.
5. Automotive SCRM, Modeling, Methods, and Tools

Motivated by the requirements of real-world practice, SCRM has attracted increasing attention from academia and industry (Tang, 2006; Simchi-Levi et al., 2014). This section provides a review of SCRM, modeling, methods, and tools for the automotive industry.

5.1 Optimization Mathematical Modeling

Optimization modeling is one of widely used quantitative approaches used to manage automotive supply chain risk. These models include the following:

- linear programming (Kırılmaz and Erol, 2017, Caux et al., 2006), nonlinear programming (Zhang and Zhu, 2012, Cedillo-Campos, et al. 2017), mixed integer programming (Häntsch and Huchzermeier, 2016; Ghadge et al., 2017), mixed integer nonlinear programming (Rezapour et al., 2017; Mohammaddust et al., 2017), and stochastic models (Nakashima et al., 2014)
  - multi-objective models (Almasi et al. 2019; Yoon et al. 2018; Häntsch and Huchzermeier, 2016);
  - game theory (Naini et al., 2011; Swinney and Netessine, 2009); and
  - newsvendor models (Nakashima and Sornmanapong, 2013).

Kırılmaz and Erol (2017) developed a linear programming model for a procurement plan by considering the cost criterion as the first priority and the risk criterion as the second priority to mitigate supply-side risks. The proactive approach to SCRM is applied to an international automotive company.

Dal-Mas et al. (2011) presented a multi-echelon mixed integer linear program (MILP) model for strategic design and investment capacity planning of the biofuel ethanol supply chain under price uncertainty. Linear/mixed integer multicriteria optimization models were used by Elmaraghy and Majety (2008) for determining the identified supply chain design parameters in an automotive power train supply chain design. Mixed integer nonlinear (MINL) models were used by Rezapour et al. (2017) to find the most profitable resilient network and risk mitigation policies and by Mohammaddust (2017) to evaluate risk mitigation strategies for a four-tier SC in a competitive automotive supply chain. Aoyama et al. (2019) used integer programming model to study the forward-reserve allocation problem considering parts combinations in a warehouse of an automotive factory. Häntsch and Huchzermeier (2016) presented a multiperiod, multi-objective optimization model that enables robust production network and location planning during times of increased market uncertainty and risk exposure in the automotive industry.

Almasi et al. (2019) developed a multiobjective sustainable supplier selection and order
allocation model considering risk and inflation. 6 objective functions including total cost, economic score, environmental score, social score, inflation rate, and risk level along with related constraints are optimized in the model. Weighted sum approach and augmented constraint method are used to solve the model.

Opritescu et al. (2019) presented an optimization model for short-term production control in a distributed environment. In their approach, production scheduling and logistics are integrated in order to enable optimal capacity utilization by releasing overall network resources with minimal overall financial expenses.

Nakashima and Sornmanapong (2013) used the newsvendor model to determine the optimal order quantity to maximize the expected profit under different scenarios. Nakashima et al. (2014) studied stochastic inventory control systems with consideration for the view of second-tier semiconductor suppliers in automotive industries using a simulation approach.

Game theory was used by Naini et al. (2011) to design a mixed performance measurement system for environmental supply chain management that measures and evaluates business operations. The authors applied their proposed method to a case study of the supply chain of one of Iran's biggest automotive companies, SAIPA. Swinney and Netessine (2009) applied game theory to model a contracting game.

5.2 Quantitative-Based Strategies

5.2.1 Supply Chain Coordination and Cooperation

Because the automotive supply chain is a multilayer, complex network, effective coordination between supply chain members is very important for risk management.

Belzowski et al. (2006) surveyed the difficulties faced by automotive manufacturers and suppliers in managing their supply chains. With thousands of Tier-1 to Tier-N suppliers located across the globe, it is very critical for automotive companies to develop and execute internal integration and external collaboration strategies to survive challenges and to mitigate supply chain risks.

Pernot and Roodhooft (2014) conducted a retrospective case study of an automotive supplier relationship and investigated whether management control system design of supplier relationships is associated with good performance. Matsuo (2015) focused on a case of supply disruption of the automotive microcontroller units after the 2011 Tohoku Earthquake, which took three months for Toyota to recover to its pre-earthquake production level, to identify what functions are missing in the supply chain coordination mechanism of Toyota Production System. Montshiwa et al. (2016)
conducted a quantitative study that included supply chain cooperation as a term in their business continuity plan. The results of 75 automobile parts markers in disaster-prone regions (Asia and North America) were studied. Friday et al. (2018) studied collaborative risk management literature which is a part of supply chain risk management. They identified six capabilities are relevant to collaborative risk management. Their research can be applied to automotive industry. Murphy et al. (2019) studied that Advanced Driving Assistance Systems (ADAS) and Autonomous Vehicle (AV) caused increase recalls. They suggested a closer, more strategic cooperation between insurance companies, car manufacturers and automotive suppliers to mitigate the recall risk. Urbaniak (2019) studied the importance of risk factors affecting relations with suppliers. The empirical method was used to study 300 producers from the automotive and other sectors operating in the Polish B2B market. The study found that Cooperation between business clients and their suppliers certainly contributes to forming long-term mutually beneficial relationships between partners, such as, to eliminate potential errors associated with new product and mitigate the risk of safety and environment, to increase the partners’ technological and organizational capabilities. Brusset and Bertrand (2018) studied hedging weather risk and coordinating supply chains. Climate change has caused the rise of weather variability. Their approach can transfer weather risks to risk takers and reduce sales volatility using weather index-based financial instruments. An automotive company which manufactures car replacement parts was used as a case study to illustrate action design.

5.2.2 Dual Sourcing

Dual sourcing is an important strategy to mitigate supply chain risk. Thun and Hoenig (2011a) pointed out that building up redundancies is an important way to create a resilient supply chain. They statistically analyzed survey data from 67 automotive manufacturing plants in Germany and concluded that dual sourcing or multiple sourcing is a valid and reliable factor in ASCRM. Davarzani et al. (2011) studied strategies of single, dual, and multiple sourcing to handle potential disruptions. They proposed a sourcing model and demonstrated it in the decision-making process for a supply chain in the automotive industry.

5.2.3 Supply Contracts

Supply chain contracts are used to coordinate supply chain members, OEMs, and suppliers to align their individual interests with those of the supply chain system and to achieve optimal supply chain efficiency. Supply chain contracts also play an important role in supply chain members sharing
risks arising from various sources of uncertainty, such as demand, price, and product quality. Considerable research work has focused on pricing strategies and order allocation in multi-supplier systems.

Dubey et al. (2018) provided analytical framework for sustainable supply-chain contract management. They applied constrained optimization techniques to model the objective function and compare five supplier-engagement contract policies. Ghadge et al. (2017) studied a supply chain risk-sharing contract to mitigate demand uncertainty and price-volatility-related risks in a globalized business environment. Selviaridis and Norrman (2014) studied performance-based contracting (PBC) in service supply chains. Swinney and Netessine (2009) investigated short-term contracts, long-term contracts, and dynamic contracts under the threat of supplier default for automotive manufacturing. Game theory was applied to model a two-period contracting game with two identical suppliers, a single buyer, deterministic demand, and uncertain production costs.

5.2.4 Supplier Selection

Supplier selection strategies have been identified as vital for risk mitigation in automotive companies (Chen et al., 2016). Multiple-criteria decision-making techniques such as fuzzy quality function deployment (FQFD), the mathematical modeling and analytical hierarchy process (AHP) (Kull and Talluri, 2008; Sharma and Bhat, 2012; de Oliveira et al. 2017), and the analytical network process (ANP) (Palanisamy and Zubar, 2013) are popular approaches used to evaluate as well as to select suppliers in the automotive industry. Phumchusri & Tangsiriwattana, (2019) applied AHP and integer programming to study optimal supplier selection model with multiple criteria in the automotive parts industry.

Yoon et al. (2018) studied models for supplier selection and risk mitigation using multi-objective optimization-based simulation and the data from an automotive parts manufacturer. Chen et al. (2016) presented an automotive company case study and evaluated the results through weighted goal programming (WGP) and preemptive goal programming (PGP) methods. Cagnin et al. (2016) evaluated supplier selection methods in the automotive industry compared with the identified models in the literature.

5.2.5. Contingency Strategies

Risk management strategies in supply chains can be divided into two categories: mitigation strategies and contingency strategies. The former focuses on taking precautions in advance of risk occurrence through strategic inventory and dual sourcing. The latter refers to the set of actions taken in post-disaster conditions, such as contingency rerouting and revenue management (Tomlin, 2006).
Contingency rerouting is a cost-effective risk management strategy for major disruptions such as natural disasters.

Grötsch et al. (2013) investigated antecedents that support proactive SCRM implementation from a contingency theory perspective. The hypotheses were developed and tested via content analysis in 63 interviews with representatives from the automotive industry. Svensson (2004) examined key areas, causes, and contingency planning of corporate vulnerability in supply chains for a subcontractor in the automotive industry.

MacKenzie et al. (2014) modeled a severe supply chain disruption and post-disaster decision-making process and applied the model to a simulation based on the 2011 Japanese earthquake and tsunami, which caused closure of several facilities of key suppliers in the automobile industry and subsequently supply difficulties for both Japanese and US automakers.

Giard and Sali (2014) studied optimal stock-out risk for a component in an automotive supply chain. In addition to the theoretical models, the simulation approach is used in automotive supply chain disruption research (Lalwani et al., 2006; Canbolat et al., 2008; MacKenzie et al., 2014).

5.3 Qualitative Approaches

5.3.1 Empirical Approach

Most research in automotive SCRM employs the empirical approach to analyze the risk and assess the risk management strategies qualitatively. González-Benito et al. (2013) concluded that the empirical approach includes three types: case studies, surveys, and secondary sources. They found that ~60% of research on automotive supply chain risk employed the empirical approach, some of which combined different methods, such as case studies and surveys or case studies and mathematical modeling.

Thun and Hoenig (2011a) and Thun et al. (2011b) conducted an empirical analysis of SCRM practices based on a survey of 67 manufacturing plants in German automotive industry. Their study identified supply chain risks by analyzing their likelihood to occur and their potential impact on the supply chain. Through analyzing managing uncertainty in small and medium-sized enterprises (SMEs), they found that SMEs predominantly focus on reactive instruments that absorb risks through creating redundancies instead of preventing risks.

Some researchers used empirical approaches for conducting regional ASCRM studies (e.g., Ceryno et al. (2015) for the Brazilian automotive industry, Sharma and Bhat (2014a, 2014b, 2016), Sharma et al. (2017), Shenoiet et al. (2018) and Prashar & Aggarwal (2019) for the Indian automobile industry, Doran et al. (2007) for the French automobile industry, Towill et al. (2000) for the European
automotive supply chain “health check” procedure, Singh et al. (2005) for the Australian automotive manufacturing industry, Vanalle et al. (2019) for supply chains with tier 1 and 2 companies in the Brazilian automotive industry and Blos et al. (2009) for the Brazilian automotive and electronic industries, Zhang et al. (2018), Lin and Zhou (2011), Xie et al. (2009), and Barclay (2008) for the Chinese automotive industry supply chain, and Shimizu et al. (2013) and Chino et al. (2017) for the Japanese automotive industry). Their research offered an initial profile and revealed insight into regional automotive industry SCRM and helped to improve it.

In addition, there is some research (e.g., Lippert and Forman (2006)) employing the empirical approach to study tiers of ASCRM. Lippert (2008) tested theoretical models through a survey of hundreds of supply chain members using an information technology innovation for part-level visibility and logistics operation along the entire first tier of a major US automotive supply chain.

Davarzani et al. (2015) used the case study method to study the influence of economic and political risks (EPRs) to supply chains. They interviewed SC professionals for three cases from an automotive SC. Sroufe and Curkovic (2008) utilized case-based research for a sample of firms in the automotive industry to examine the ISO 9000:2000 standard and supply chain quality assurance. de Oliveira et al. (2017) verified that ISO 31000:2009 can be used as a standardized method to perform SCRM. They developed a pathway to apply ISO 31000:2009 risk assessment tools and techniques to integrate a procedure for SCRM based on AHP and provided an automotive supply chain example. Cagnin et al. (2019) studied assessment of 9001: 2015 implementation, which is the most recent version as part of the assured quality concept evolution. Their research focus on risk management approach requirements compliance in an automotive company using case-based research. They also suggested a checklist for assessing the ISO 9001: 2015 risk management requirements compliance.

5.3.2 Risk Mitigation Strategies

- **Build a Resilient Supply Chain**

Hohenstein et al. 2015 defined “Supply chain resilience is the supply chain’s ability to be prepared for unexpected risk events, responding and recovering quickly to potential disruptions to return to its original situation or grow by moving to a new, more desirable state in order to increase customer service, market share and financial performance”.

A resilient supply chain is critical to the success of an enterprise (Hsieh et al., 2016). Building such a supply chain to mitigate uncertainty is a priority for automotive companies (Chen, et al. 2016). Recently, supply chain managers have changed their main focus from reducing costs to improving SC continuity and resiliency (Kırlmaz and Erol, 2017). Rezapour et al. (2017) studied resilient supply chain network design under competition using a real-life case study in an automobile SC. They
recommended three policies used to mitigate disruption risk: keeping emergency stock at the retailers, reserving backup capacity at the suppliers, and multiple sourcing. Lotfi and Saghiri (2018) studied and examined the impact of resilience by a structural model. The model is tested with the data from 151 automotive parts suppliers. The results show that a higher level of resilience will improve the performance in terms of delivery, cost and time to recovery, however it does not have a remarkable impact on flexibility performance.

- Increase Flexibility and Robustness

   Flexibility is commonly associated with the ability to change or react. Owing to the importance of flexibility for achieving a competitive advantage and mitigating risks, researchers increasingly study how entire supply chains can deliver flexibility to their customers. Flexibility includes production diversification, geographic diversification, increased overall flexibility, flexible input sourcing (e.g., dual sourcing), backup suppliers, localized sourcing, flexible supply contracts, flexible manufacturing, and flexible distribution (Ceryno et al., 2015; Chopra and Sodhi, 2004; Tomlin, 2006; Chopra and Meindl, 2010; Thun and Hoening, 2011a).

   Thomé et al. (2014) studied supply chain flexibility in the automotive industry based on empirical research on three Brazilian automotive supply chains.

   Robustness has been conceptualized as a dimension of supply chain resilience. Durach et al. (2015) defined it as “the ability of a supply chain to resist or avoid change”, and provided a systematic review for supply chain robustness. They called for researchers to conduct more quantitative approaches and derive more reliable practical applications. Wieland and Wallenburg (2012) explored the relationship between SCRM, agility/robustness, and performance by case studies. They surveyed 270 German manufacturing companies including auto manufacturers, and found that SCRM is important for agility and robustness of a company. Both agility and robustness can improve performance. Robustness can help to deal with supplier-side risks, while agility is necessary to deal with customer-side risks. Bhavana Raj and Srinivas (2019) developed a conceptual model and validated it for supply chain management and supply chain robustness. They collected survey data from 126 organizations of the automotive sector. Their empirical study shows that the robustness of Supply chain has a positive impact on the performance of the supply chain.

   Manzini and Urgo (2019) proposed an approach for the robust design of a reconfigurable assembly cell to cope with the uncertainty of the automotive spare part manufacturing requirements. The robustness is carried out by minimising a function of the risk related with investment and operational costs of the assembly cell.

- Rethink the Global Supply Chain
During recent years, offshoring and outsourcing have transformed automotive sectors into global networks of design, production, and distribution across the global value chains (Bailey and De Propris, 2014). Many Asian and Eastern European countries, with cheap and skilled labor, offer attractive opportunities for reducing supply chain costs. However, these globalization and outsourcing opportunities come with significant risks, including cultural and linguistic differences, foreign exchange rate fluctuation, duty and custom regulations, quality problems, and political and economic stability. The weaknesses and risks inherent in such global value chains have been exposed, triggering attempts to rethink their nature and also raising possibilities to insource some manufacturing activities to home countries. Bailey and De Propris (2014) studied reshoring for opportunities and limits for manufacturing in the UK automotive sector. Thun and Hoenig (2011a), Richardson (2005), Sharma and Bhat (2014b), Canbolat et al. (2008), and Zimmer et al. (2017) identified globalization risks in the automotive industry.

- **Implement Green Supply Chain Management**

As the public becomes more aware of environmental issues and global warming, the environmental and social impact of supply chains has attracted considerable research attention. Green supply chain management (GSCM) has emerged as an important organizational philosophy and a proactive approach to reduce environmental risks. Automotive supply chain managers have been considering and implementing GSCM practices to improve both their economic and environmental performances (Diabat et al. 2013).

There has been considerable research on GSCM for the automotive industry (Fernando et al. (2018), Lee and Cheong (2011), Lee (2011), Munguía, et al. (2010), Diabat et al. (2013), Govindan et al. (2014), Azevedo et al. (2012) and Caniëls et al. (2013)). Some theoretical frameworks and empirical approaches for the analysis of the influence of green and lean upstream supply chain management practices on business sustainability have been proposed.

### 5.4 Practical Tools in ASCRM

Proactive SCRM can lead to greater customer satisfaction, lower total cost, improved delivery performance, and higher quality outcomes. Some practical tools have been developed for SCRM that have shown promising application results in automotive industries.

#### 5.4.1 Risk-Exposure Model

Simchi-Levi et al. (2014, 2015) developed a new risk-exposure model to identify risks and mitigate disruptions in the automotive supply chain quantitatively. Unlike traditional SCRM methods, which rely on knowing the likelihood of occurrence and the magnitude of impact for every potential
event that could materially disrupt a firm’s operation, they developed a mathematical model that focuses on the impact of potential failures at nodes along the supply chain, rather than the cause of the disruption. In their model, a supply chain network was created first. Each node stands for a supplier facility, a distribution center, or a transportation hub. There are three parameters that need to be determined for each node: (1) time to recovery (TTR) or time-to-survive (TTS), (2) performance impact (PI), and (3) the risk exposure index (REI), which ranges between 0 and 1. Simchi-Levi et al.’s model allows companies to effectively identify areas of hidden risk in the supply chain.

5.4.2 Failure Mode and Effect Analysis

Failure mode and effect analysis (FMEA) has been suggested as an SCRM tool (Canbolat et al., 2008; Curkovic, et al. 2013; Rewilak, 2015; Sharma and Bhat 2014b; Pandey and Sharma, 2017). FMEA is commonly used in the automotive industry to collect information related to risk management decisions in an engineering capacity, but not typically in a supply chain capacity.

Based on FMEA, Canbolat et al. (2008) used a process failure mode effect analysis (PFMEA) structure to characterize the risks and developed a simulation model to quantify risk factors so that an automotive OEM can evaluate risk mitigation strategies. Curkovic et al. (2013) surveyed 67 industrial companies, including four automotive OEMs, and found that some companies used the FMEA model for selecting and assessing suppliers. Pandey and Sharma (2017) applied an FMEA-based interpretive structural modeling approach to model automotive supply chain risk.

5.4.3 Multiple-Criteria Decision-Making Models

Multiple-criteria decision making (MCDM) or multiple-criteria decision analysis (MCDA) has also been used for risk assessment in the automotive industry, such as in supplier ranking and selection (Kull and Talluri, 2008; Palanisamy and Zubar, 2013; Datta et al., 2013; Neumüller et al., 2016; Jasiński et al. 2018).

Blackhurst et al. (2008) developed a multicriteria scoring procedure to create risk indices for parts and suppliers in the automotive industry. Diabat et al. (2013) explored using a fuzzy MCDM method for green supply chain practices and performances in the automotive industry. Datta et al. (2013) utilized fuzzy logic in an MCDM process for evaluation and selection of third-party reverse logistics providers for an automobile part manufacturer.

Other ASCRM research topics include managing risks in JIT and sequence supply networks (Wagner and Silveira-Camargos, 2012), lean process supply chains (Cervi, 2007; Azevedo et al., 2012), optimized programming by resource management (Hanenkamp, 2013), entrepreneurial SCM competence and performance (Hsu et al., 2011), natural hedging as a risk prophylaxis and supplier
financing instrument (Hofmann, 2011), and an economic P-chart model to mitigate quality risks (Sun et al., 2012).

Other practical tools in ASCRM include a strategic materials positioning matrix (SMPM) (Saueressig et al., 2017). Using a case study method, SMPM was applied to two families of items (bolts and plastic finishing) purchased by an automotive industry company in southern Brazil. The materials were organized by SMPM into four classes: noncritical, strategic, risk, and competitive. The result of the analysis showed significant reduction of shortages in the assembly line and storage facility units required for warehousing.

Carnovale et al. (2019) studied Buyer-Supplier relations for automotive OEM and Tier 1 suppliers about supplier’s compensation for price concessions and the role of organizational justice. They found when supplier grants price concessions to an OEM, it would reduce quality and R&D expenditures toward that OEM, and the organizational justice can improve negative supplier compensatory activities.

5.5 Summary

A summary of the literature reviewed for risk management in this paper is shown in Figure 5. The SCRM research methodologies reviewed are given in Table 4.

6. Conclusions and Future Research

This study reviewed the existing research work on ASCRM. We first classified the risks into 10 categories and discussed risk assessment methods, and then focused on summarizing the research on ASCRM’s mathematic modeling, quantitative approaches, qualitative approaches, and practical tools.

In the modeling approach, optimization models are widely used including linear and nonlinear programming, mixed integer programming, and multi-objective models. Newsvendor models are used for formulating the problem with uncertain demands, and game theory is also employed for supply chain coordination and supply contracts.
Figure 5. Summary diagram of the literature reviewed for risk management in this study.

Qualitative approaches include empirical approaches and risk mitigation strategies. The empirical approach is so popular in ASCRM research that about 60% of the research employs it to analyze risk and to assess risk management strategies qualitatively (González-Benito et al., 2013). In addition, some new research trends in risk mitigation strategies can be applied to the automotive supply chain; these include building a resilient supply chain and implementing green supply chain management. Some practical tools such as multiple-criteria decision making methods, FMEA and PFMEA simulation models, and risk-exposure models have been utilized to mitigate risk in automotive supply chains.

The major conclusions from this study of ASCRM are as follows: (1) Research on ASCRM has been increasing in recent years. (2) The main mathematical models include optimization models, such as linear and nonlinear programming, mixed integer programing, multi-objective optimization models, newsvendor models, and game theory; tools such as value at risk and conditional value at risk have rarely been used. (3) The automotive industry recognizes the importance of ASCRM and expends considerable effort on its investigation but academic research is thus far insufficient. (4) The automotive industry has a very complex, multitier SCM and the risk sources of automotive supply chains are widespread. (5) There are some practical tools and risk mitigation strategies, such as MCDM and FMEA, but there is a lack of real-time risk alarm systems and tools for supply chain resilience.

Based on the reviewed papers in ASCRM, we propose a few important future research directions as follows:
1) Study and development of systematic methods and systems to analyze ASCRM by mitigating risks caused from multiple different sources: The automotive supply chain is a huge multitier supplier network. Most research work in the automotive industry is based on specific points of views, i.e., the supplier’s or manufacturer’s. There is no systematic method of system to analyze and integrate different ASCRM strategies, such as how to choose supply locations, transportation, to optimize the objectives for both manufacturers and suppliers as a system and to reduce geographic or political risks in the automotive supply chain in the global environment. The existing research on the impact on the automotive network resulting from supply chain risk has not been sufficient. This area requires more related research to be conducted in the future.

2) Use of data- and big-data-based ASCRM: One of the major automotive supply chain risks is nontransparency resulting from the multiple layers in the supply chain. Typically, OEMs have substantial data about Tier-1 suppliers, but they lack data from Tier-2 to Tier-N suppliers. Nontransparency makes it very difficult to monitor risks and issue warnings. Big-data analytics can provide a basis for transparency in automotive supply chains. With the help of real-time big data availability, OEMs and suppliers can improve their supply chain transparency, monitor the occurrence of risks, provide early warnings and responses, and enable managers use the developed risk mitigation strategy to prevent the risks. Big-data-based sense-and-respond systems for ASCRM are worth further research.

3) Study of the downstream risks to the automotive supply chain: There is not enough research on automotive-industry-specific models. The special aspect of the automotive supply chain is its complexity owing to the huge number of multitier suppliers and globalized network. Further study is required on downstream risks to the automotive supply chain besides demand uncertainty, such as call-back risk and how to build a resilient network.

4) Implementation of more quantitative models: Through a literature review, we found that the majority of research on automotive supply chain risk employs empirical approaches. There is a real demand in the automotive industry to use quantitative models to evaluate supplier risks in terms of different tiers and different type of suppliers. Various mathematical models have been developed to assist in planning under uncertainties with simplified real-life situations (Singhal et al., 2011). Proposed future work includes quantitative model development for complex ASCRM and improvement of the mathematical models to cope with real-life situations. Traditional risk modeling, including use of the utility function, variance, standard
deviation, mean–variance, value at risk, and conditional value at risk, has rarely been applied to ASCRM. These modeling methods can be applied to ASCRM.

5) Addressing advanced technology challenges: In recent decades, revolutions in information technology and telecommunications has brought about dramatic changes in our daily lives and in the automotive industry as well. Automakers continuously offer new high-technology features in their products (e.g., GPS, telematics, various sensors, ADAS, RFID, etc.). These high-technology features present many technological challenges in the automotive supply chain. One of these challenges is the risk posed to vehicle design, production, quality, and after-sales services by the short product development cycle and the long useful life of vehicles. Automotive manufacturers must mitigate risk through their component suppliers. Future research needs to be done on car manufacturers' selection of proper suppliers and on improving coordination and corporation among supply chain vendors.

6) Research on autonomous cars and car-sharing services: In recent years, autonomous cars have emerged as the future of the automotive industry. Experts have predicted that fully autonomous cars will arrive to the market by 2025 to 2030 (Li, 2016). Car-sharing services using autonomous vehicles could be attractive for many private buyers as well. It is suggested that new-car sales in the US could be eroded by as much as 40%. Like any new product, autonomous cars will have demand uncertainty because of many obstacles, such as adoption rate, technological challenges, liability disputes, laws, and regulations. Demand uncertainty implies overcapacity risk or undercapacity risk. Future work includes improving forecast accuracy to optimize contracts and production capacity and to reduce supply chain risk.

References


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