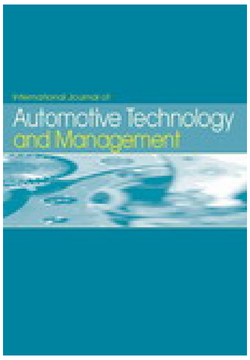

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Empirical analysis, mapping and prioritisation of supply chain risk - Indian automotive context

Aditya Gautam, Asif Akhtar, Mrinalini Shah, Usha Gautam

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Empirical analysis, mapping and prioritisation of supply chain risk – Indian automotive context

Aditya Gautam

Vitesco Technologies Germany GmbH,
Neumeyerstr. 50, D-90411, Nürnberg, Germany
and
Department of Business Administration,
Faculty of Management Studies and Research,
Aligarh Muslim University,
Aligarh India
Email: gautamaditya30@gmail.com
Email: 2014HT79223@wilp.bits-pilani.ac.in

Asif Akhtar

Department of Business Administration,
Faculty of Management Studies and Research,
Aligarh Muslim University,
Aligarh, India
Email: asifakh@gmail.com

Mrinalini Shah

Institute of Management Technology,
Raj Nagar, Ghaziabad, Uttar Pradesh, 201001, India
Email: shahmrinalini@gmail.com

Usha Gautam*

Department of Mechanical Engineering,
Friedrich-Alexander University,
Immerwahrstraße 2a, 91058,
Erlangen, Germany
Email: ushaditya30@gmail.com
Email: usha.aitpg@gmail.com
*Corresponding author

Abstract: Supply chain risk management has become a crucial topic of interest for both academics and professionals, owing to the ever-changing and complex nature of the contemporary business environment. The challenges posed to sustainability have forced businesses to rethink their strategies, and it is imperative to prioritise supply chain risks to ensure their long-term success. This article aims to study the Indian automobile supply chain empirically and explores the various supply chain risks from the articles published between 2010 and 2024 and subsequent brainstorming sessions with 25 industry practitioners. After discussion and feedback from industry experts, an online survey was distributed to the industry professionals. A total of 100 responses were collected. Finally, the feedback from expert panels and survey results are used to calculate the risk priority number (RPN) to prioritise each risk using the failure mode and effect analysis (FMEA) approach. Based on RPN value, the risks are classified into three classes: high, medium and low. In our study, we found that the automobile industry is largely impacted by external supply chain risk, and therefore seeks the constant attention of industry experts to secure their supply chain from the adverse effect of these risks.

Keywords: automobile industry; empirical analysis; failure mode and effect analysis; FMEA; India; supply chain risk; survey; brainstorming.

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Biographical notes: Aditya Gautam is a senior purchasing and supply chain professional and currently working as Manager in Advanced Purchasing at Vitesco Technologies Germany GmbH, Nürnberg, Germany. He has more than 18 years of experience in project purchasing, supply chain management, and category management in various automotive MNCs. He received his MTech in Manufacturing Management from the BITS Pilani, and BE in Mechanical Engineering from the Dr. B.R. Ambedkar University, Agra. He also completed the Advanced Diploma in Management from the All-India Management Association (AIMA), Delhi and the Post Graduate Diploma in Materials Management from the Indian Institute of Materials Management, Mumbai. Currently, his research areas include supply chain management, strategic management, supplier selection, risk management, resilience, and multi-criterion decision modelling.

Asif Akhtar received his PhD in Management and MBA in Business Administration from the Faculty of Management Studies and Research, Aligarh Muslim University. He completed his BTech in Mechanical Engineering from Z.H.C.E.T, Aligarh Muslim University, Aligarh. He is currently working as an Assistant Professor in the Department of Business Administration at Aligarh Muslim University, Aligarh. He has a rich experience in teaching, industry, and research for more than 16 years. His research areas include quantitative techniques in management, operations management, and Islamic banking. He has published several research papers in reputed national as well as international journals.

Mrinalini Shah is a Professor of Operations and Supply Chain Management at the Institute of Management Technology, Ghaziabad and is the Founder of Management Veda. She has earned a Doctorate in Computer Science and Postdoctoral Research in Supply Chain from Warsaw University Poland. Her education experience includes Harvard Business School, USA, and St. Galleon University Switzerland. She is a CSCP Fellow and a Stanford Venture and NEN Certified Entrepreneurship Educator. She is a recipient of state, national and international scholarships for merit including the European Commission Postdoctoral fellowship. Her research interests are supply chain strategy, supply chain sustainability, inventory management, and digital supply chain. She has many international peer-reviewed research publications to her credit. She was awarded second best women researcher by AIMS-international and won twice, the best research paper award in national conferences.

Usha Gautam received her PhD in Microwave Engineering from the Faculty of Technology, University of Delhi, and her MTech in RF and Microwave Engineering from the Ambedkar Institute of Technology, Guru Gobind Singh Indraprastha University, Delhi. She completed her BTech in Electronics and Communication Engineering from Uttar Pradesh Technical University, Lucknow. She is currently studying MS in Electromobility at Friedrich-Alexander University Erlangen-Nuremberg. She has a rich experience in teaching, industry, and research for more than ten years. Her research areas include microwave differentiators and integrators, and microwave antennas and recently developed her interest in supply chain management topics. She has published several research papers in reputed international journals.

1 Introduction

The concept of risk is a multifaceted and extensively studied subject in various business contexts. However, in today's dynamic business environment and vulnerable, uncertain, complex and ambiguous (VUCA) world, building a solid foundation for sustainable growth is a challenging task due to ever-evolving new risks and uncertainties (Azevedo et al., 2013; Mubarik et al., 2023). There have been significant uncertain incidents for decades. These incidents have impacted the supply chain badly and contributed millions and billions of financial burdens on overall profitability with unrecoverable losses of millions of dollars of the many organisations and lives across various industries (Fahimnia et al., 2015; González-Zapatero et al., 2021). The consequences of supply chain risk might be tangible (humanitarian, financial, and business losses) and intangible (loss of reputation and bad corporate image). The major reasons behind growing and ever-emerging risks are increased global transformation within automotive industry (Ghafs and Elabjani, 2024), higher quality expectations (Ruiz-Benítez et al., 2018), natural disasters, human deliberate acts, political differences between countries (Li et al., 2020; Shekarian and Parast, 2021), and climate change (Singh et al., 2019). When such disruption occurs, the automobile industry becomes particularly susceptible because of the expanded dimensions of supply chain risks due to increased globalisation; new regulations to address climate change (Midler and Alochet, 2023), outsourcing, low inventory reserves on account of just-in-time and cost-minimisation practices, shorter product life cycles, and increased competition (Scholten et al., 2014; Aslam et al., 2020). Therefore, managing supply chains has become increasingly challenging and crucial for manufacturers to follow best practices to achieve global standard quality, cost, and delivery up to customer expectations (Soon and Udin, 2011). It is critical to build resilient supply chains that can withstand these disruptions. Therefore, researchers, academicians, and practitioners show a growing interest in safeguarding business continuity, competitive advantage, and sustainable growth (Fahimnia and Jabbarzadeh, 2016; Mohammed et al., 2021; Gu et al., 2021; Sauer et al., 2022; Statsenko et al., 2024).

The topic of supply chain risk management has been addressed by many researchers, academicians, and practitioners using different tools and techniques. The basic process of supply chain risk management used by the majority of researchers is grounded upon five primary steps:

1 understanding the specific supply chain
2 identifying the associated risks
3 prioritising these risks
4 studying resilience capabilities to manage these risks according to their priorities
5 proposing the supply chain resilience framework to deal with these risks.

It is crucial to prioritise the identification and prevention of potential hazards and risks in systems and processes. This is especially true when it comes to uncertainties and unforeseen events, as swift action can prevent accidents from occurring altogether. Therefore, to successfully navigate the complexities of the Indian automotive industry, it is vital to prioritise supply chain risks (Tian et al., 2024). By doing so, one can ensure that the operations are optimised, costs are minimised, and disruptions are avoided. Therefore, this study mainly focuses on addressing the first three (of five) primary steps discussed and being addressed in this paper to understand the automobile SC, to identify and map and prioritise the risks, a brainstorming session with industry experts, an industry survey and finally using the FMEA approach. The primary steps 4 and 5 could be investigated through further research. The basic idea of the brainstorming session was:

1 to discuss and review the outcome of the literature review with industry practitioners
2 to get the industry insight and understanding of the automobile supply chain and risks
3 to map these risks in pictorial form to increase the visibility of supply chain and their risk together
4 to discuss and identify the detection (D) criteria for each risk identified through literature survey.

To ensure the utmost objectivity and minimise bias in our research, we conducted a highly selective and rigorous brainstorming session with a group of 25 industry experts. We handpicked a diverse range of professionals from various automobile companies in India based on their extensive industry experience of at least ten years, as well as their academic qualifications in engineering or management at the bachelor's or master's level. Our selection criteria ensured that the session was conducted with the highest level of academic integrity. Additionally, to prevent any potential conflicts of interest, no more than one expert was invited from any given company. Of the 25 experts in attendance, three were from original equipment manufacturers (OEM), six were from original design manufacturers (ODM), eight were from tier-1 companies, and eight were from tier-2 companies. In addition to the brainstorming session with automobile industry practitioners, a questionnaire survey was developed in such a way as to get the severity (S) and occurrence (O) for each risk identified through the literature review phase and expert panel consultation and distributed to professionals working in automobile companies in India.

2 Methodology

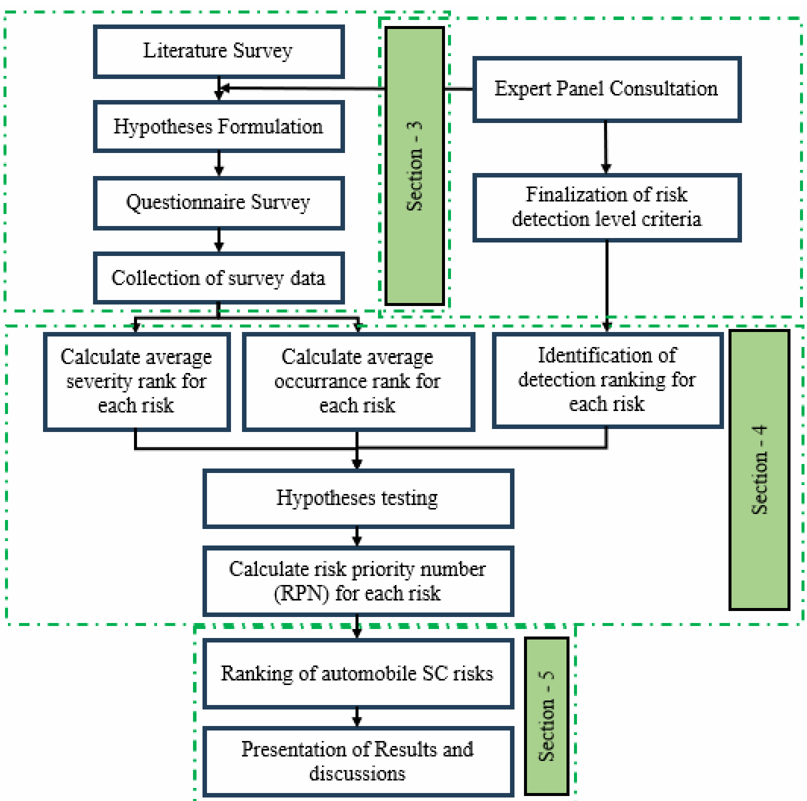
The remainder of the manuscript is divided into three sections. Figure 1 displays the process flow diagram (PFD) integrating a variety of academic management and engineering techniques. The manuscript provides actionable insights to mitigate the four risk categories identified: external environment, external supplier risk, internal risk, and distribution/network risks.

Section 3 of the manuscript includes a literature survey, brainstorming session, hypotheses formulation, questionnaire distribution, and data collection. These activities help identify the severity, occurrence, and detection criteria for each risk.

Section 4 of the manuscript includes calculating the average severity and occurrence of each risk, testing hypotheses, and calculating the risk priority number. These sections help prioritise risks and provide actionable insights for managers in the automotive supply chain industry.

Section 5 of the manuscript concludes the research findings by prioritising and clustering the risks, managerial implications, and limitations of the research.

Figure 1 Process flow diagram for research methodology (see online version for colours)



3 Literature review

3.1 Automotive supply chain

The supply chain is a crucial aspect of facilitating the distribution, transportation, and transshipment of goods and services within SC networks (Lim et al., 2017; Li and Zobel, 2020). In many cases, SC is used interchangeably with logistics and refers to the movement of goods and services. The SC has been discussed in various contexts, including digital, global, humanitarian, pharmaceutical, service, oil and gas, maritime, agribusiness, manufacturing, automobile, bioethanol, multi-tier, blood, resilient, and sustainable SC.

In essence, the supply chain (SC) is a conceptual framework that links multiple SC networks of different companies, including suppliers and end customers. By coordinating efforts to optimise overall value to the organisation, the SC integrates supply and demand (Soon and Udin, 2011; Gligor, 2016; Rojo-Gallego-Burin et al., 2020; Esmaeilikia et al., 2016; Ivanov and Dolgui, 2020). The network serves as a channel through which information, goods, and services flow. While SC has different definitions, all SC networks must have at least two nodes, one for receiving inputs and another for delivering outputs in the form of goods, services, or information (Kumar et al., 2022). These nodes can be tangible or intangible and may include virtual platforms for information exchange. In the automotive industry, the SC comprises a diverse set of suppliers, intermediaries, and third-party service providers working together to serve the end customer, with information, goods, and services moving through interconnected nodes and networks. Because of these interdependent complexities (Gong et al., 2014; Yavari and Zaker, 2019; Goldbeck et al., 2020) in the automotive supply chain, the following hypothesis is formulated:

H1 The automotive supply chain is regarded as being vulnerable to supply chain risks.

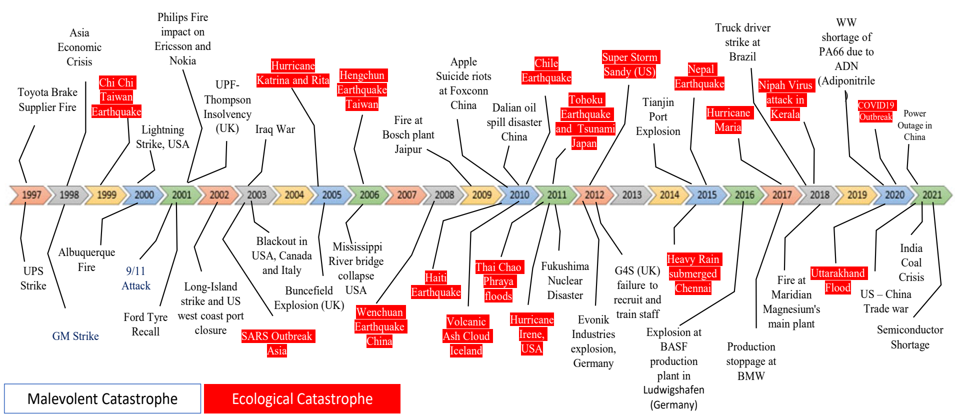
Through extensive literature analysis and collaboration with industry experts, we developed a comprehensive understanding of the fundamental building blocks of the automobile supply chain. These building blocks include various levels of supply chain partners, their corresponding stock-keeping locations, and the modes of transportation used to move goods. Additionally, we identified and analysed the numerous risks present within and outside of the supply chain. Our findings are represented in a consolidated in schematic diagram as shown in Figure 3 that depicts the flow of goods, services, and information, as well as the associated risks and uncertainties, throughout the automotive supply chain between OEM, ODM, tier 1 and tier 2 companies.

3.2 Supply chain risks

In today's business landscape, it is crucial to consider the risks associated with uncertainties, as they can have a significant impact on project outcomes (Esmaeilikia et al., 2016; Shishodia et al., 2019; Haeri et al., 2020). Uncertainties can come in various forms, including environmental (Gligor et al., 2016; Sreedevi and Saranga, 2017; Rojo et al., 2018), demand (Das, 2011; Song et al., 2018), capacity (Altendorfer, 2017; Kaur et al., 2020), economic (Childerhouse et al., 2020; Zouari et al., 2021), behavioural (Dubey et al., 2017), epistemic (Sabouhi et al., 2018) and yield (Ye et al., 2018) uncertainties, as explored by numerous researchers. It is worth noting that, while the terms ‘uncertainty’ and ‘risk’ are often used interchangeably, they have distinct meanings. Uncertainty refers to a lack of information about the decision situation, which requires judgement to evaluate alternate solutions and potential outcomes. As such, it is essential to recognise how risk and uncertainty interact and integrate (Gligor, 2014; Yu et al., 2018; Chaudhuri et al., 2018). Making the wrong decision can result in unforeseen, unfavourable, or mixed outcomes – that is what we refer to as risk.

For decades, various uncertain incidents have greatly impacted the SC and resulted in millions and billions of financial losses for organisations and lives across multiple industries (Hall et al., 2010; Kochan and Nowicki, 2018; Oliveira et al., 2019). The disruptions such as the Volkswagen emission scandal (2015); an explosion at the BASF production plant in Ludwigshafen, Germany (2016); production halt at BMW plants in Germany, China and South Africa due to missing Bosch parts (2017); Nipah virus attack in the Indian state of Kerala, fire at Meridian Magnesium’s main plant, truck driver strike in Brazil (2018); worldwide shortage of PA66 due to ADN (Adiponitrile), COVID-19 outbreak (2020), US-China trade war, cyclone Jawad and cyclone Gulab in Odisha and Andra Pradesh, power shortages in China, coal crisis in India and worldwide semiconductor shortages (2021) and Russia-Ukraine war (2023) remind us that we live in an unpredictable world. Therefore, our business is highly exposed to a myriad of potential risks. Figure 2 maps out the major malevolent and ecological catastrophes that have disrupted the SC in the last two decades.

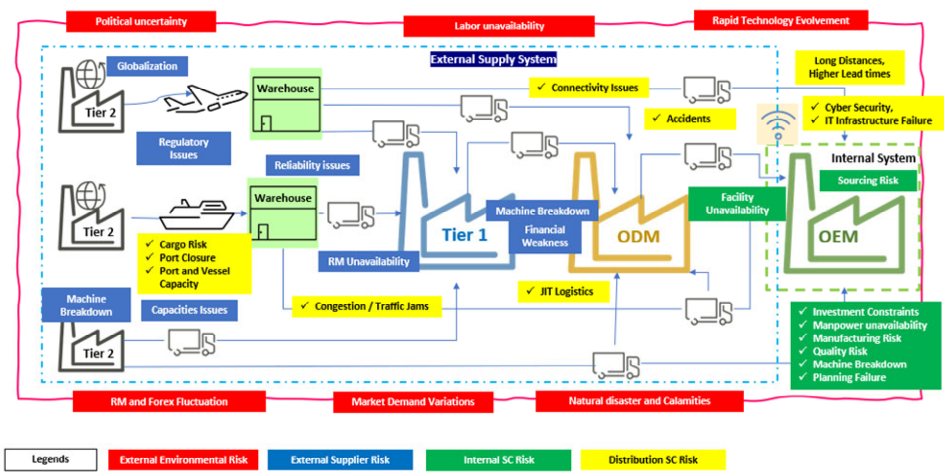
Figure 2 Major supply chain disruptions (see online version for colours)



Source: Author’s own creation

Figure 3 plots four types of risks: external environmental risks, external supplier risks, internal supply chain risks, and distribution-related risks. External environment risks are those that are generally beyond the control of any given industry and include raw material and forex fluctuations (Bhattacharya et al., 2013), labour unavailability (Das and Lashkari, 2015; Rezapour et al., 2017; Mohammed et al., 2019), demand variations (Um and Han, 2021), political uncertainty (Tukamuhabwa et al., 2015), rapid technological advancement (Sabouhi et al., 2020), and natural disasters (Wieland and Wallenburg, 2013; Gligor et al., 2019). External supplier risks are also known as sourcing risks. They can arise from capacity issues (Pereira et al., 2014), machine breakdowns (Singh et al., 2019), raw material unavailability (Bevilacqua et al., 2020), unreliable sub-suppliers (Kamalahmadi and Mellat-Parast, 2016), poor financial strength (Kochan and Nowicki, 2018) and regulatory delays in supplies (Liu et al., 2018). To mitigate or minimise the impact of these risks, customers can exert direct influence on sub-supplier companies through robust supplier selection and regular supplier audits during serial production. Internal supply chain risks refer to risks that exist within the company at various stages of product development and internal supply chain, such as machine breakdowns (Um and Han, 2021), design uncertainty (Hasani and Khosrojerdi, 2016), planning failures (Skipper et al., 2014), investment constraints (Bevilacqua et al., 2020), and unavailability of manpower (Singh et al., 2018) and infrastructure facilities (Al-Shboul, 2017). Finally, distribution or network-related risks exist at various stages of the transfer of goods and information between suppliers and customers and include issues such as traffic jams, cargo damages, IT system failures, warehouse inadequacies, and complex multi-party supply chains (Gautam et al., 2018).

Figure 3 Schematic diagram of a typical automobile supply chain (see online version for colours)



Source: Author's own creation.

Following the identification of potential risks, it is important to assess their likelihood of occurring and the impact they could have on the entire supply chain (Thun and Hoenig, 2011). While it can be challenging to precisely quantify these factors, it is recommended to evaluate each identified risk at least qualitatively.

The prevailing assumption that external environmental risks pose a greater severity to the SC compared to the other risks (external suppliers, internal supply chain, and distribution risks) is supported by various studies. External risks, such as political instability, natural disasters and economic fluctuations are beyond the control of supply chain managers, making them particularly severe compared to internal risks (Sáenz et al., 2018). On the other hand, external supplier risks are believed to have a higher probability of occurring than external environmental, internal supply chain, and distribution risks (Piprani et al., 2022). Building on this understanding, we have developed hypotheses that draw connections between the likelihood and severity of risks in the automobile supply chain.

H2 The external environmental risks are more severe than an external supplier, internal supply chain, and distribution/network-related risks in automobile supply chain risks.

H3 The external supplier risks have a higher likelihood of occurrence than external environmental, internal supply chain, and network-related distribution risks.

4 Failure mode effect analysis (FMEA)

The failure mode effect analysis (FMEA) is an engineering technique that is paramount in identifying, defining, and eliminating known or potential failures, problems, and errors from a system, design, process, or service before they can even reach the customer (Wu et al., 2021). FMEA is an indispensable aspect of reliability engineering and is extensively used in the automotive and aerospace world. It is particularly effective in improving design for new developments, technologies, components, assemblies, or products with inherent issues. The first and foremost step in conducting an FMEA involves identifying potential failure modes and determining their ultimate effects through the expertise of a group of professionals from various disciplines. Once all failure modes are listed, they are assessed and prioritised based on their risk priorities using the traditional FMEA approach, which calculates the risk priority number (RPN) as the product of occurrence (*O*), severity (*S*) and detection (*D*) of a failure according to equation (1).

$$RPN_i = O_i \times S_i \times D_i \tag{1}$$

where *O* and *S* are the occurrence frequency and severity level of the failure and *D* is the ability to detect the failure before it reaches the customer. The evaluation of the three parameters is conducted on a 5-point scale, resulting in an RPN score ranging from 1 to 125. Failure modes with higher RPN scores are of greater significance and require prioritised attention in the design process to mitigate or eliminate any potential risks.

Table 1 Severity, occurrence, and detection criteria

Rating	*Severity*		*Occurrence*		*Detection*	
1	Very low	Very less impact	Very low	Very low frequency of risk, i.e., rare events such as once in a six month	Very low	Continuous data for prediction or trends are available with the market, research firms, and companies
2	Low	Slight disturbance or impact	Low	Low frequency event such as once in a month	Low	Discrete data for prediction is available in society and companies
3	Medium	Medium impact	Medium	Medium frequency of risk events such as once a week	Medium	Fragile data or trends by experience, incidents, etc.

Table 1 Severity, occurrence, and detection criteria (continued)

Rating	*Severity*		*Occurrence*		*Detection*	
4	High	Significant impact on business	High	High frequency of risk events such as more than once a week	High	Fairly poor detection due to lack of data (guess about the situation)
5	Very high	Very high impact on business and human life	Very high	Continuous risk events such as everyday or more than once a day	Very high	Absolutely no prediction is possible

According to the FMEA guidelines, the lesser the ranking the better the detection system in place, and vice-versa. The outcome of the panel for severity, occurrence, and detection criteria is summarised in Table 1.

4.1 Research design

To create the questionnaire, we first conducted extensive research and brainstorming sessions with 25 industry practitioners. We used the well-known 5-point Likert scale to gather feedback on the severity and occurrence of each identified risk. The survey instrument underwent multiple stages of development and was pre-tested by academic experts and experienced purchasing executives. A member of our research team worked closely with each company representative to review the survey in person and through various forms of communication to ensure clarity and consistency with business practices and terminology. The final questionnaire was distributed to 546 industry professionals working with various automobile companies in India in April 2021 using the surveymonkey.com platform. After one month, we sent two bi-weekly reminders to the respondents with no response to the survey. In total, we received 100 usable responses out of 546 distributions, with a strike rate of 18.31%, which we refined to serve our research purpose. The data, presented in Table 2, shows that the majority of respondents belong to original design manufacturers (ODMs), followed by 1st tier companies. Additionally, 97% of respondents have more than 10 years of experience, and the data reflects a balanced participation of junior to senior management levels in their organisations. We observed that 91% of respondents belong to functions such as business development, purchasing, operations, and supplier quality, and are directly or indirectly responsible for supply chain management in their day-to-day responsibilities. Around 83% of industry practitioners reported that their responsibilities mainly involve dealing with mechanical commodities in their respective organisations.

Table 2 Respondent/company data

1 Type of companies of respondents	
OEM	3
ODM	40
Tier 1	34
Tier 2	23

Table 2 Respondent/company data (continued)

2 Function of respondents	
Business development and sales	35
Purchasing and supply chain management	28
Production and operations	18
Supplier quality and quality management	9
Project management	5
Research and development	3
Finance and accounting	1
3 Focus of respondents responsibilities/companies	
Electronics	17
Mechanical	83
4 Role of respondents in organisation	
Junior management	44
Mid management	26
Senior management	30
5 Year of experience of respondents	
Less than 10 years	3
Between 10 to 15 years	18
Between 15 to 20 years	32
Between 20 to 30 years	29
More than 30 years	18

4.2 Calculation of risk priority number

To determine the vulnerability, respondents were asked for their estimation of the severity and occurrence of the risks on the five-point Likert scale. The outcome of the survey data and expert panel discussion in the form of severity, occurrence, and detection is presented in Table 3. Based on pre-defined criteria, the detection value is assigned to each risk with a certain argument recorded during the brainstorming session. For example, the detection rating of raw material and forex fluctuation is very high due to its absolute prediction-based forecast based on widely available market data at various trading centres and platforms such as the London Metal Exchange (LME) for raw materials and Xe for forex. Similarly, the detection rating for ecologic and malevolent catastrophes is very low due to their unpredictable nature. Finally, the risk priority number (RPN) is calculated by multiplying the severity, occurrence, and detection for each risk. The average value of severity and occurrence is also calculated in Table 4.

Table 3 Calculation of risk priority number (RPN)

Risk type	*Online survey results*			*Outcome of brainstorming session with purchasing experts from industry*			*RPN*
	Risks	*Severity (S)*	*Occurrence (O)*	*Detection rate*	*Remarks*	*Detection (D)*	
External environmental supply chain risks	Raw materials and forex fluctuations	3.58	4.28	Very high	Absolutely predictable based on past raw material data trends and fluctuations	1.00	15.32
	Labour unavailability	3.26	3.14	High	Fairly predictable from seasonal data (higher during festival seasons)	2.00	20.47
	Market demand variations	3.30	3.38	High	Fairly predictable from seasonal data (higher during festival seasons)	2.00	22.31
	Political uncertainty	3.09	2.04	Moderate	Moderately predictable based on global and national political situations	3.00	18.91
	Rapid technology evolvement	2.70	2.97	Moderate	Moderately predictable based on geographical technology evolvement	3.00	24.06
	Natural disaster and calamities, attacks, accidents	4.37	2.05	Very low	Absolutely unpredictable	5.00	44.79
External supplier risks	Machine breakdown	3.53	3.23	Moderate	Moderately predictable based on equipment life and previous maintenance history	3.00	34.21
	Supplier capacity issues	3.50	3.10	High	Fairly predictable based on PPAP results, regular supplier audits, frequent capacity checks	2.00	21.70
	RM unavailability at supplier	3.09	3.06	Moderate	Moderately unpredictable based on supply and demand calculations, stock calculations. Sometimes difficult to predict due to global material shortages	3.00	28.37
	Sub-supplier reliability issues	3.02	3.38	Moderate	Moderately predictable based on regular supplier audits, automotive certification (IATF 16949, ISO 19001) and financial situation of the suppliers and sub-suppliers (balance sheets, P&L statements)	3.00	30.62
	Bad financial strength of the supplier	2.93	2.87	Moderate	Moderately predictable from financial statements (balance sheet, P&L)	3.00	25.23
	Regulatory delays (i.e., import goods, complex tax structure)	2.64	2.42	High	Fairly predictable by regular experience with authorities	2.00	12.78

Table 3 Calculation of risk priority number (RPN) (continued)

Risk type	*Online survey results*			*Outcome of brainstorming session with purchasing experts from industry*			*RPN*
	Risks	*Severity (S)*	*Occurrence (O)*	*Detection rate*	*Remarks*	*Detection (D)*	
Internal supply chain	Machine breakdown	3.30	2.97	Moderate	Moderately predictable based on equipment life and previous maintenance history	3.00	29.40
	Design uncertainty	3.05	2.78	Low	Fairly low predictable due to everchanging customer, market and regulatory requirements	2.00	16.96
	Planning failure	3.28	2.61	Moderate	Moderately unpredictable due to delay in precedence activities	3.00	25.68
	Investment constraints	2.56	2.70	High	Fairly predictable. Well-known facts about financial constraints	2.00	13.82
	Manpower unavailability	3.19	2.44	High	Fairly predictable from seasonal data (higher during festival seasons)	2.00	15.57
	Facility unavailability	2.46	2.18	High	Fairly predictable. Well-known facts about facilities constraints	2.00	10.73
Distribution/ network supply chain risks	Traffic jams	2.87	2.54	Low	Fairly low predictable due to lack of road infrastructure, accidents	4.00	29.16
	Cargo damage	2.50	2.26	Very low	Absolutely unpredictable during consignment duet to bad weather, terrorist attacks	1.00	5.65
	IT system failure	3.10	2.75	Very low	Absolutely unpredictable during consignment duet to bad weather, terrorist attacks	1.00	8.53
	Warehouse inadequacies	2.28	2.33	High	Fairly predictable. Well-known facts about facilities constraints	2.00	10.62
	Long, multi-party pipelines or supply chains	2.86	2.69	High	Fairly predictable from past data and supply behaviour	2.00	15.39

Table 4 Average severity, occurrence, and risk priority number

Risk type	*Average severity*	*Average occurrence*
External environmental supply chain risk	3.38	2.98
External supplier risk	3.12	3.01
Internal supply chain risk	2.97	2.61
Distribution/network supply chain risks	2.72	2.51
Overall	3.05	2.78

4.3 Prioritisation and clustering of risks

The prioritisation of each risk based on its RPN value is outlined in comprehensive Table 5. Through the expert panel discussion, we have categorised these risks into three clusters: high, medium, and low risk. Our clustering methodology is based on a ±25% deviation from the mid-value of the RPN (15.63) and shown in Figure 4.

The clustering methodology employed in this study is based on a ±25% deviation from the RPN mid-value, which is 15.63. This deviation range was selected to ensure that the categorisation is precise and accurate.

To further analyse the results, the study assigned priority rankings to each risk. The top twelve risks, assigned priority rankings of 1 through 12, are classified as high-risk items, indicating that they require immediate attention and mitigation. These risks include natural disasters and calamities, machine breakdowns, sub-supplier reliabilities, raw material unavailability at suppliers, demand variations, and bad financial strength of suppliers, among others.

The following seven risks, with priority rankings 13 through 19, have been grouped under medium risk. These risks include political uncertainty, design uncertainty, long and multiparty supply chains, raw material, and forex fluctuations, among others. Finally, the last four risks, with priority rankings 20 through 23, have been classified as low risk in the automobile supply chain. These risks include facility unavailability, warehouse inadequacies, IT system failure, and in-transit cargo damage. In conclusion, the study provides valuable insights into the prioritisation of risks in the automobile supply chain and can be used by industry professionals to identify, assess, and mitigate risks effectively.

Figure 4 Risk clustering scale (see online version for colours)

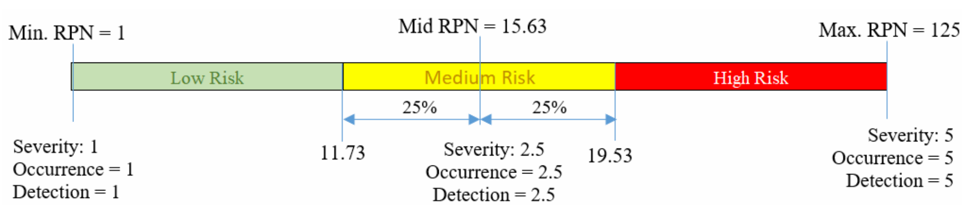


Table 5 Prioritisation and clustering of automobile supply chain risks

Risk type	*Risks*	*RPN*	*Priority*	*Risk class*
External environmental	Natural disaster and calamities, attacks	44.79	1	High
External supplier	Machine breakdown	34.21	2	High
External supplier	Sub-supplier reliability issues	30.62	3	High
Internal supply chain	Machine breakdown	29.40	4	High
Distribution/network	Traffic jams	29.16	5	High
External supplier	RM unavailability at supplier	28.37	6	High
Internal supply chain	Planning failure	25.68	7	High
External supplier	Bad financial strength of the supplier	25.23	8	High
External environmental	Rapid technology evolvement	24.06	9	High
External environmental	Market demand variations	22.31	10	High
External supplier	Supplier capacity issues	21.70	11	High
External environmental	Labour unavailability	20.47	12	High
External environmental	Political uncertainty	18.91	13	Medium
Internal supply chain	Design uncertainty	16.96	14	Medium
Internal supply chain	Manpower unavailability	15.57	15	Medium
Distribution/network	Long, multi-party supply chains	15.39	16	Medium
External environmental	Raw material and forex fluctuations	15.32	17	Medium
Internal supply chain	Investment constraints	13.82	18	Medium
External supplier	Regulatory delays	12.78	19	Medium
Internal supply chain	Facility unavailability	10.73	20	Low
Distribution/network	Warehouse inadequacies	10.62	21	Low
Distribution/network	IT system failure	8.53	22	Low
Distribution/network	Cargo damage	5.65	23	Low

5 Discussion and conclusions

According to the data gathered, the average values of risk severity and occurrence are 3.05 and 2.78 among all respondents. A significant portion of participants (almost 63%) perceive their supply chain as moderate to highly vulnerable (point 3 or 5 on the scale) to supply chain risks. In comparison, 37% of managers estimated their supply chain as being very low to low susceptible to supply chain disruptions (point 1 or 2 on the scale). Overall, it can be concluded that the vast majority of managers (almost 63%) do not consider their supply chain vulnerability to be low, therefore, as a result, Hypothesis H1 cannot be refuted.

Furthermore, it is evident from the data that the average severity of external environmental supply chain risk (3.38) is higher than external supplier risk (3.12), internal supply chain risk (2.97), and distribution risk (2.72), which means external environmental risks have more severe impact on the overall sustainability of the supply chain as compared to external supplier, internal supply chain and network related risks.

We noticed that natural disasters and various kinds of malevolent attacks (4.37) have a more severe impact than any other kind of risks within the external environment risks. Hence, Hypothesis H2 cannot be rejected.

Similarly, it is also evident that external supplier risks have a higher likelihood of occurrence (3.01) than external environmental (2.98), internal supply chain (2.61), and network-related distribution (2.51) risks, which indicate that external supplier risks occur more frequently than other types of risks. However, we noticed that the majority of managers accepted that raw material and forex fluctuations are the most frequent risk with an occurrence of 4.28 on a point Likert scale as compared to the frequency of other types of risks. Hence, Hypothesis H3 cannot be rejected.

5.1 Managerial implications

The manuscript provides valuable insights into the automobile supply chain industry and associated risks. It discusses an automobile supply chain, including OEM, ODM, tier 1, and tier 2, and maps all possible risks to provide a high level of understanding to audiences. The manuscript involves a significant number of industry professionals at various levels through expert panel discussions and industry surveys to make it more pragmatic in dealing with the various kinds of risks in the automobile supply chain. The FMEA tool used for ranking and prioritisation of these risks is widely used in all automobile companies regardless of company size. Therefore, the manuscript offers an innovative, easy-to-understand, and cost-effective approach, especially for smaller companies with limited resources (tier-2 or less) to manage and interpret the risk impacts for industry professionals.

The risks are ranked according to their RPN and prioritised into low, medium, and high-risk categories. By prioritising these vulnerabilities, companies can take necessary steps to minimise the impact of disruptions based on their priority and protect their supply chain.

According to empirical analysis, supply chains are vulnerable to risks due to the lack of proper risk management measures. Moreover, supply chains are becoming increasingly complex due to various external environmental, external supplier, internal and network-related supply chain risk factors, which further increase their vulnerability. Globalisation, for instance, creates dependencies that can cause risks on both the demand and supply sides. Similarly, product variations can create uncertainty, and outsourcing can heighten the number of interfaces and dependence between companies, making the supply network more susceptible to risks. Reducing the number of suppliers can create a dependency while offshoring increases the vulnerability of supply chains due to cross-national connections that can lead to faults.

In addition to the aforementioned drivers, we examined the resulting supply chain risks. Our analysis indicates that potential risks to supply chains are evaluated based on their likelihood of occurrence, severity on the supply chain, and detection resources. Our findings suggest that external environmental and supplier risks are more likely to occur and would have a greater impact on the supply chain and, therefore, have been ranked as a high-risk category. We noticed that ecological and malevolent catastrophes have poor or no predictability, and therefore companies may still face significant losses. However, the amount of loss can be reduced by implementing proper proactive resilience strategies. Furthermore, our results also show that many of the risks that supply chains face originate from within the supply chain itself. This highlights that managers have the ability to take direct action to mitigate these risks. Therefore, it is of utmost importance to implement proper resilience strategies to safeguard supply chains and prevent losses (Gautam et al., 2023).

5.2 Limitations

The manuscript highlights certain limitations that should be considered. With the rise of electronic, telematics, and electrical drives, the percentage of electronics in a new car has significantly increased, accounting for approximately 35 to 40% of the total car value (Gautam et al., 2023). Our industry survey showed that only 17% of respondents participated from electronics purchases/manufacturing industries. As a result, further analysis could be conducted on specific electronics component manufacturers within the Indian automobile industry.

It should be noted that the survey was solely distributed to Indian automobile companies, which limits its scope to the Indian automobile industry. To gain a more comprehensive understanding, an international survey could be conducted to provide valuable insights and allow for comparative empirical analysis of the global automobile industry.

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Glossary

OEM	Original equipment manufacturers.
ODM	Original design manufacturers.
FMEA	Failure mode and effect analysis.
VUCA	Vulnerability, uncertainty, complexity and ambiguity.
PFD	Process flow diagram.
SC	Supply chain.
ASC	Automotive supply chain.
RPN	Risk priority number.
O	Occurrence.
S	Severity.
D	Detection.