An Empirical Study of Supply Chain Frangibility and Risk Management in Indian Automobile Industry

Arora Ankit
ABV-Indian Institute of Information Technology and Management (ABV-IIITM), Gwalior, India
Rajagopal Rajesh (rajeshambzha@gmail.com)
Indian Institute of Space Science and Technology

Research Article

Keywords: FMEA (Failure Mode Effect Analysis), BWM (Best Worst Method), supply chain frangibility, responsiveness

Posted Date: May 25th, 2021

DOI: https://doi.org/10.21203/rs.3.rs-475609/v1

An Empirical Study of Supply Chain Frangibility and Risk Management in Indian Automobile Industry

ARORA, ANKIT
Management Division, ABV-Indian Institute of Information Technology and Management (ABV-IIITM), Gwalior, India
Email: ankit.arora801@gmail.com

RAJAGOPAL, RAJESH*
Management Division, ABV-Indian Institute of Information Technology and Management (ABV-IIITM), Gwalior, India
Email: rajeshambzha@gmail.com; rajesh@iiitm.ac.in
ORCID: **0000-0002-4231-0539**

Biographical note:

Ankit Arora is a post-graduate student in Management with specialization in Operations Management at the ABV- Indian Institute of Information Technology and Management (ABV-IIITM), Gwalior, India. His research areas of interest are decision-making, risk management, vulnerability, and resilience.

Rajesh is presently working as Assistant Professor (Operations Management) in ABV- Indian Institute of Information Technology and Management (ABV- IIITM), Gwalior, India. Prior to joining there, he worked as a Post-Doctoral Fellow in the Department of Management Studies (DoMS) in Indian Institute of Technology Madras (IIT-M), India and he has completed his Ph.D. from the Indian Institute of Space Science and Technology (IIST), India. He is working the areas of supply chain risk management, resilience, sustainability, and environmental management.

corresponding author

An Empirical Study of Supply Chain Frangibility and Risk Management in Indian Automobile Industry

Abstract: The automobile sector in India is one the key segment of Indian economy as it contributes to 4% of India's GDP and 5% of India's Industrial production. The supply chain of any firm is generally dependent on six driving factors out of which three are functional (information, inventory, and facilities) and 3 are logistic (sourcing, pricing, and transportation). The risk causing factors in supply chains consists of various levels of sub-factors under them. Say for instance, under supply risk, the sub-factors can be poor logistics at supplier end, poor material quality etc., under demand risk, the sub-factors can be inaccurate demand forecasting, fluctuating demand, bullwhip effect, and under logistics risk, the sub-factors can be poor transportation network, shorter lead time, stock outs. Through this study, we observe to find the effect of these factors in the supply chain. We use Failure Mode and Effect Analysis (FMEA) technique to prioritize the various types of risk into zones namely high, medium and low risk factors. Also, we use the Best Worst Method (BWM), a multi-criteria decision-making technique to find out the overall weightings of different risk factors. The combination of these methods can help an organization to prioritize various risk factors and proposing a proper risk mitigation strategy leading to increase in overall supply chain efficiency and responsiveness.

Keywords: FMEA (Failure Mode Effect Analysis), BWM (Best Worst Method), supply chain frangibility, responsiveness.

1. Introduction

The supply chain plays a prominent role in every business activity and is basically related to desired flow of goods and services between various parties involved in supply chain system. The macro environment of every business these days is rapidly changing. Recent advancements in technology, change in customer preferences, globalization, changing legal and government policies, as well as concern for the environment has increased a lot of activities to look for in a supply chain. This has involved many types of risk elements at various stages of supply chain, which are impeding the overall efficiency and responsiveness of a supply chain. Thus, in order to make supply chain more responsive and efficient, we need to identify the areas of risks and mitigate risk strategies to overcome them. From this context, supply chain frangibility and supply chain risk management (SCRM) comes into the picture.

Supply chain risk acts as a function of probability of an event's occurrence and its impact on areas of supply chain. There are number of risk areas present in the overall supply chain. To mitigate these risks, supply chain risk management (SCRM) comes into influence. SCRM is the actual implementation of the risk mitigation strategies to manage various types of external/ internal risks in the supply chain, based on a continuous risk identification approach with aim of reducing frangibility and improving overall supply chain responsiveness and efficiency (Radivojević and Gajović, 2014). As we know, supply chain management is the act of managing information, processes, capacity, service performance and funds from the available supplier to the desired customer (Chopra, Meindl, and Kalra, 2013).

The study evolves around identifying the risk areas across the supply chain of Indian automobile industrial firms, primarily around the areas of inbound logistics, sales and operational planning, and outbound delivery. In order to find out the areas of risks in automobile industry and thus coming up with suitable risk mitigation strategy, we have considered two main risk types, of which one is external risks which the firm has no direct control. These include risks such as demand risk, supply risk, environmental risk, legal risk, technology risk, disruption risk etc., and other is the internal risk, which firm can control better, which includes risks such as information risk, Information Technology (IT) system risk, logistics risk, financial risk, operational risk, security risk, workforce behavior risk etc. (Elleuch, Hachicha, and Chabchoub, 2014). All these risk factors can be occurring at any point in a supply chain (Rajesh, 2018). The major areas along with the possible risks under that area are explained in with the help of cause and effect diagram (fish bone diagram), as shown in Figure 1.

1.1. External SC risk

These risks in supply chain are due to the elements of macro environment and the firm has no direct control over them. The intensity of risk caused by them is essential for a firm to identify so as to protect its business activities. These includes various types of risks namely the demand risk, supply risk, legal risk, environmental risk, technology risk, disruption risk, etc. (Cagliano *et al.*, 2012).

a) Demand risks

Demand risks are basically the potential for the loss due to the gap between the forecast and actual demand of commodities required by customers. These basically occur due to disruptions that occur in downstream operations (Liao *et al.*, 2019). These are either due to transportation issues, bullwhip effect, uncertain surroundings factors, and so on. The common risk parameters under demand risks are fluctuating demand, seasonal demand, bullwhip effect, demand volatility, fuzzy customer demand, etc.

b) Supply risks

Supply risks lead to disruption of business by supplier's network (Helbig *et al.*, 2018). Organizations generally face various risks from suppliers due to their bargaining power, financial instability, poor quality, purchasing risk, poor logistics factors, and so on.

c) Legal risks

These risks are generally due to negligence of laws of business or during any part of supply chain (Zubarev, 2020). They can be at any stage of supply chain and include risks such as compliance risks, regulatory risks, industry tariffs etc. These risks are very important for effective operations of supply chain and must be taken care by all the concerned parties of supply chain.

d) Environmental risks

These risks in supply chain are due to various macro elements like, change in geographical regions, climatic conditions, global warming factors, environmental regulations and many more (Li and Wang, 2019). The supply chain of any firm has to deal with these risks by adopting a proper strategy and risk mitigation plans.

e) Technological risks

These risks are the potential for any technology failure that disrupts supply chain activities by introducing various risks into the supply chain (Tosun, 2017). These risks include various risk sub factors such as service outages, data theft, information security incidents, new technology introduction etc.

f) Disruption risks

Also known as catastrophic risks, these risks generally occur due to natural calamities or manmade ones such as economic crisis etc. They affect the supply chain of a firm and operations as whole. The factors to these risks includes risks due to natural disasters, such as flood, drought, etc., and manmade activities such as nuclear war, 9/11 attacks, global price wars, epidemics or diseases, like COVID-19 and others (Xu *et al.*, 2020).

1.2. Internal SC risks

These risks are the ones that are internal to the firm and can be controlled by the firm well by aligning its management and operational activities in a better way. These includes risks that occur due to change in management structure, operational activities etc. The various risks that come under it are IT system risks, logistics risks, financial risks, operational risks, security risks, facility risks, workforce behavior risks, etc.

a) IT system risks

IT system plays an important role in sharing the product related information, logistics information, etc., and integrating different parties of supply chains by providing an integrated network interface. Breakdown of IT system and poor IT infrastructure within a firm can hamper the vital information sharing and thus reduce the overall responsiveness and efficiency of a supply chain (Thöns, 2018). The various sub parameters under IT risks can be system breakdown, poor infrastructure, obsolete IT technology; IT related information security issues etc.

b) Operational risks

Operational risk are the ones that are resultant of various activities within a firm's overall operational areas that impact its ability to produce goods and services, including their quality, production standards, and scheduling, manufacturing capabilities and delivery schedule as well (Araz *et al.*, 2020). The various risk factors that come under operational risks that hamper the organization efficiency are product quality issues and defects, product failure risk, process failure risks, etc.

c) Logistics risks

Logistics consists of activities related to storage, movement, and delivery of goods in raw materials (RM) or finished form to concerned parties. Logistics risks are generally from both supplier and distributor side and to the firm itself (Choi *et al.*, 2019). The logistics risks are cause of delays in order shipment, RM and finished goods delivery, increased lead time, stock outs etc. The various risk parameters under logistics risk can be poor transportation network, delay in transportation, driver shortage, theft issues, poor capacity planning etc.

d) Financial risks

These risks can be induced at any stage during a supply chain, either due to improper budget allocations, wrong financial moves, constructive changes, loss of money etc. The possible risk factors that fall under cluster of financial risks are bankruptcy, budget overruns, missed milestones requiring extra funding, improper budget allocations, etc. (Silva, Kimura, and Sobreiro, 2017).

e) Security risks

These risks generally occur at any stage of supply chain and are the ones that threaten the operations integrity, human values and information misuse. These may lead to various kind of risks such as stolen of valuable data, freights frauds, vandalism, crime, sabotage etc. (Nurse, Creese, and De Roure, 2017).

f) Workforce behavior risks

These are generally the resultant of human allied errors. They can occur both due to inaccurate knowledge, poor planning and scheduling, improper forecasting, poor judgments and bad decisions, and also due to injury / illness or departure of key personnel (Low *et al.*, 2019). These risks are the most difficult to access under the supply chain.

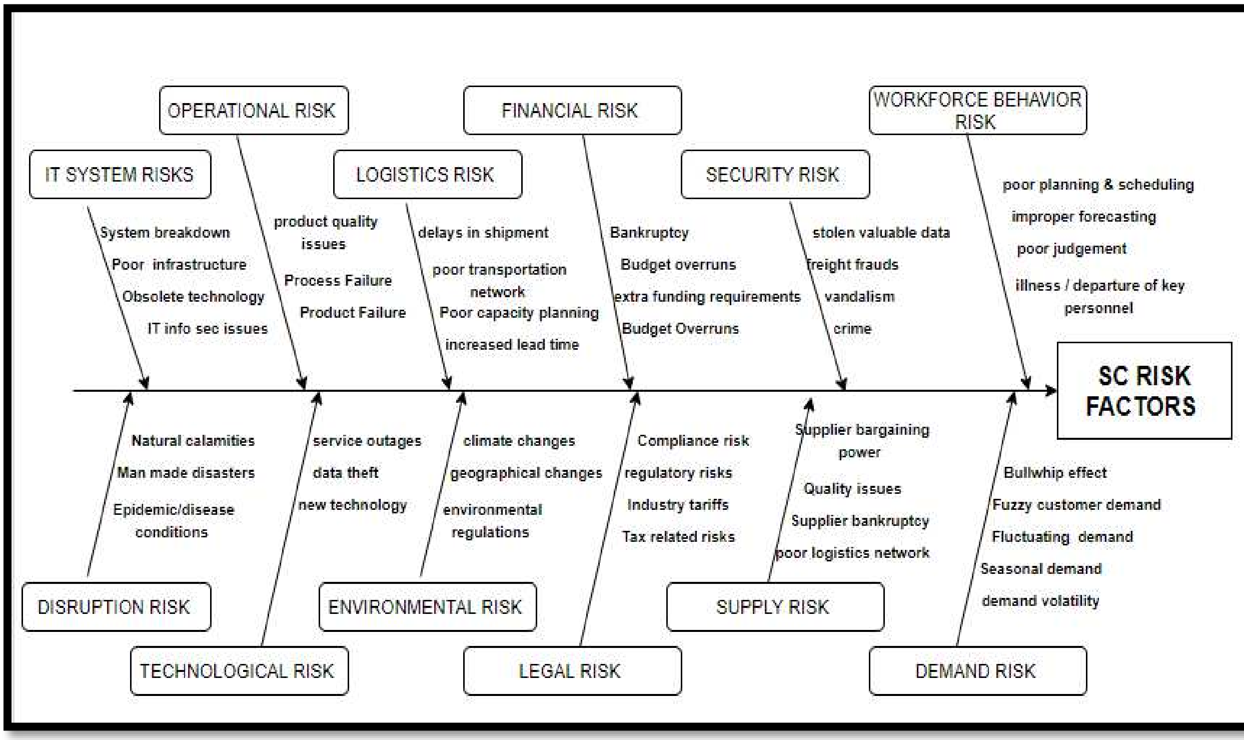

Figure 1: Cause and effect diagram of possible internal and external defects (adapted from Chopra, Meindl, and Kalra, 2013)

1.3. Drivers of supply chain with associated risk

The external and internal risk causing factors are generally present at any part of a total supply chain. Also, apart from these risks factors, there are many other risks causing factors that are present in the system. The supply chain of any industry is mainly dependent on the six main drivers of Supply chain. Out of these 6 main drivers of supply chain, on which a supply chain strategy is to be formulated for achieving responsiveness and efficiency. As we see, 3 are cross functional drivers namely information, sourcing and pricing and 3 remaining are under logistics drivers namely facilities, inventory, and transportation, which is as shown in Figure 2. All these functional and logistics drivers consists of various risk causing factors and areas under them, for which the risk mitigation strategies are to be adopted by the firm in order to mitigate the effect and cause of risk that is hindering the supply chain responsiveness and efficiency .

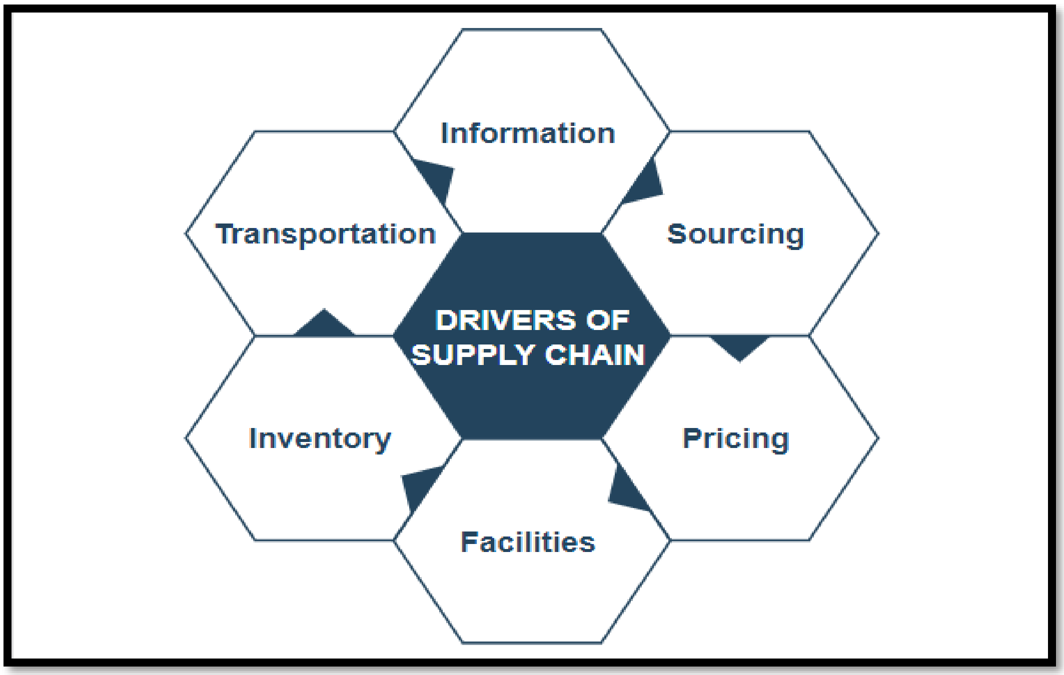

Fig 2 : Drivers of supply chain (adapted from Chopra, Meindl, and Kalra, 2013**)**

1.3.1. Information

The flow of information between parties in a supply chain is highly essential for it's responsivenss. Timely information avaliability helps in taking timely decisions and manage the supply chain related activities. Inaccurate information sharing or lack of information availability including delays, wrong sources etc. can introduce various types of risks into the supply chain and can hamper its' efficiency (Tan, Jiang, and Wang, 2019). The various risks paramaters under information part are;

a) Bullwhip effect

The bullwhip effect is basically a concept that is used for explaining the uneven inventory fluctuations that occur within the distribution channel, where demand forecast yields supply chain inefficiencies. It is generally a result of inaccurate forecasting and proper inromation unavailability as a result of which it causes swings in the inventory levels causing pile up of unwanted inventory as we move to higher levels in the supply chain network.

b) Customer data mishandling

Handling of customer data during supply chain activities is very important, as it is highly sensistive and personal to a customer and might go in wrong hands, if not properly handled. Mishandling of data by the firm may seem to customer, as their information is at threat and might tarnish the image of the company. Hence, a proper IT security system is needed.

1.3.2. Sourcing

Sourcing also known as procurement and it refers to all those activities related to purchase of RM, machinery and other things at low cost and high quality by selecting, sourcing, and evaluating the best suppliers, who can provide the desired materials at low cost, best quality and in lesser lead time. Improper approach, while performing sourcing related activities can introduce various types of risks to a firm mainly from the side of suppliers (Kumar, Basu, and Avittathur, 2018). Some of the risks causing factors are as follows.

a) Buying power of supplier

The supplier being the only one in any particular area, holding a resouce that is scarce and do not have easy replacements that dominates the whole supply chain, by making product delays and charging up high costs for the products and thus introduces various risks to a manufacturer like financial causes, product delays, and many more.

b) Supplier quality risks

The quality of any product is highly dependent on the quality of the raw material used at the initial stages . Use of low quality RM at initial stages can lead to the rejection of items durig the final stages of delivery to customers and thus tarnishing the public image of company to as someone producing products of lower quality . Moreover the low quality of RM by supplier is a cuase of various defects at several stages of operations and supply chain .

1.3.3. Pricing

Pricing plays an important role in managing responsivness and demand requirements for products that the supply chain attempt to serve. Pricing also plays an improtant role in matching demand and supply in case of inflexible supply chain. The pricing decides how much to charge for supply chain related activities and other product related activities from a customer (Choi *et al.*, 2020). Inaccurate pricing can introduce several risks parameters into the supply chain.

a) Supply surplus availaibility

Seasonal discounts and various short term discounts are given by the firm in order to cater the surplus supply, when the demand is less and uncertain. High pricing and surplus supply will cause blockage of excess of inventory resulting in losses in terms of managing and storing of these.

b) Type of demand

Pricing also affects the type of demand the company will incur for its products . When the parties in a supply chain charge high prices for various supply chain activities, the company charges it from their customers. These high prices can lead to set the type of demand that the company expects and the costs that it will incur for the products offered to their customers.

1.3.4. Facilities

Facilities in supply chain are the actual physical locations, where the product in raw form or finished form are stored and maintained as stock keeping units (SKU's). These include plants, warehouses, and facilitation centers. The placement of warehouses, their location, and capacity planning should be done in a way that it is easy to reach for their customers and other concerned parties (Zhong *et al.*, 2020). The inaccurate capacity planning and facility arrangements may induce various risk factors into the supply chain.

a) Inadequate SKU's for storage

Lack of desired stock keeping units and their availability makes it difficult for the supply chain parties to store the desired units, efficiently into a facility unit and this affects the firm's ability to match the desired demand and supply.

b) Obsolete technological infrastructure

An unavailability of technical devices and tools can introduce various risks on the facility management part into the supply chain like, there will be no proper system available for product monitoring, entry and exit, and storage related information. Also, there can be disruptions in the supply chain, causing uneven demand and supply ratios, improper material ordering, and other serious forecasting issues.

1.3.5. Inventory

Inventory means the physical stock of goods and commodities either in raw, semi-finished, and/or finished form stored at various places in warehouses or plants kept to meet the uncertain or volatile customer demand. It is kept in store for ensuring the smooth running of business processes. However, both shortage and excess of inventory can cause several types of risk in the supply chain of a business system (Jerath, Kim, and Swinney, 2017). The various risks that occur due to inventory are as follows.

a) Large supply and low demand

When the supply of the units are greater than the actual demand by the consumers, it results in the pile-up of inventory at the warehouses, thus introducing various risk and unnecessary cost into the system, like cost of storage, maintenance, inventory carrying costs, change in technology risk, locking up of money, etc., leading to making the supply chain inefficient and costly.

b) Large demand and low supply

When the demand for the products are very high and the supply of material for the same is not as per the demand required, it results in bad image for firm that it is not able to fulfill its customers' requirement and the same induces various kinds of risk into the system like risk of stock out, end of safety stocks, increase in duplicity, high prices for units etc.

1.3.6. Transportation

Transportation is actually responsible for the physical movement of goods between locations through a well-defined fleet network. It accounts for around 60% of the total supply chain investment and is associated with several risks (Baksh *et al.*, 2018). The various risks under this driving factor can be as follows.

a) Poor fleet network

Poor fleet network followed by shortage of desired fleet vehicles and qualified drivers cause delay in product delivery, thus causing increase in lead time and stock out risk at the delivery end causing stoppage of other activities of supply chain.

b) Regulatory transportation issues

Various agencies can lay various transportation rules, like Bharat Stage (BS) VI usage in India, limited carrying capacity, maintenance rules, safety rules etc., which hinders the overall speediness of the desired delivery of commodities. The rules vary from fleet to fleet and thus hindering the efficiency of supply chain to some extent.

An analysis and prioritization of the risk factors with consideration to the drivers of supply chain has not been conducted in the literature. We attempt to fill this gap by considering the case of Indian automobile industry. We employ a mixed method involving Failure Mode and Effect Analysis (FMEA) and Best Worst Method (BWM) techniques to categorize and prioritize various risk factors, which are elaborated in subsequent sections. And the paper is further arranged as follows. Section 2 details the literature review followed by the methodology and case evaluation as elaborated in Section 3. Section 4 summarizes the results, related discussions, and implications of the study, which is followed by the conclusions of the study in Section 5.

2. Literature review

An automobile supply chain is quite vast and consists of a large network of associated parties. The supply chain is highly dependent on various external and internal factors that drives it and is prone to several risks that can hamper the responsiveness and efficiency (Knobloch, Zimmermann, and Gößling-Reisemann, 2018). Several researches has been conducted in the past decades to analyze the risks that occur, factors causing the particular risk, and proposing the risk mitigation strategies to overcome the risks that affects the associated supply chains. Several models and multi-criteria decision-making (MCDM) techniques have been applied in the past by several researchers to find out the nature and areas of risks and thus coming up with suitable risk mitigation strategies to nullify the effects of risk causing factors and thus increasing the responsiveness and efficiency of a supply chain. We have conducted a study of literature in this area and some of the important works are elaborated below.

Heidari, Khanbabaei, and Sabzehparvar (2018) observed the risk factors to reduce their effect in a fuzzy environment considering organizational performance factors (OPF) and risk operational practices (ROP). Rostamzadeh *et al.* (2017) developed a framework of risk causing factors for a sustainable supply chain risk management evaluation (SSCRM) and the dominant risks were identified using CRITIC approach (criteria importance through inter-criteria correlation). Chirra and Kumar (2018) assessed the flexibility of supply chain in automobile industries and identified strategies as their overall influence are ranked and classified as cause-effect groups and the important and crucial strategies are identified with their ability to mitigate the risk causing conditions and to nullify the unseen consequences of risk causing factors. Bello *et al.* (2018) assessed the risk impact in automobile industry and various risk factors were identified and classified into groups of business risks, economic risks, and external risks. Sharma and Bhatt (2014) applied a cluster analysis approach to identify SCRM risk dimensions and explored SCRM strategies used by the firm and classified automotive firms on basis of these SC dimensions. Brief literatures on the related works are shown in Table 1.

Table 1: Supply chain research conducted in past and their relevant literature

Sl.no	Authors (s), year	Remarks
1	Heidari, Khanbabaei, and Sabzehparvar (2018)	Proposed a SCRM model in PLC and OPC and fuzzy AHP and TOPIS techniques are used to find out the desired relation and formulation method for prioritizing risk factors to decrease level of risk by finding an alternate ideal strategy.
2	Rostamzadeh *et al.* (2017)	Studied about risk causing factors for SSCRM by using CRITIC approach to know about major and minor risk causing criteria and using TOPSIS to find the desired alternate similarity to ideal risk mitigation solution strategy adoption.
3	Chirra and Kumar (2018)	Focused on improving SC flexibility by understanding studies on risk mitigation strategies, by classifying and ranking as per their overall effect on SC and observed the best risk mitigation strategies using a fuzzy DEMATEL approach.
4	Bello *et al.* (2018)	Identified different business risks and classified into categories and applied fuzzy AHP to identify major risk factor under each category and identifying the major risk factor among all.
5	Sharma and Bhatt (2014)	Applied cluster analysis approach to identify risk dimensions and using PCA to collect data and cluster variate to cluster as high and low SCRM risks factors.

3. Methodology

3.1. Failure Mode Effect Analysis (FMEA)

FMEA is basically a systematic and a proactive statistical approach used by all the companies of every sector nowadays. FMEA is a widely used statistical technique to discover all the potential failures that could happen during any process of product/services. It is widely used to identify different types of failures modes that can occur during any process. It can also be used to know the cause of those failures and the overall possible effect of the failure on system efficiency (Johnson and Khan, 2003). FMEA can be widely applied in the areas of product/service design, manufacturing, supply chain, and logistics. By using FMEA, companies can identify the different cause of failure, prioritize them on the basis of their overall effect and can limit them in various functional areas of inbound, sales and operational planning and outbound logistics.

The FMEA process includes the following processes under it which are as follows:

- Steps in a particular process of concerned areas like design, manufacturing, supply chain, and logistics etc.
- **Modes of Failure** (What could go wrong during any process?)
- **Causes of Failure** (Why is the failure happened and what could be the possible causes of such failures?)
- **Effects of Failure** (What would be the consequence of such possible failure and by how much it can impact the overall process?)

3.1.1. General Conditions for FMEA

FMEA process can be used for various purposes and in different areas of total product life cycle in an industry. It can be used by different parties in areas like product/service design, manufacturing, sales and operational planning, supply chain and logistics and many others for various purposes. The situations or conditions under which FMEA can be applied include:

- When there is a change in manufacturing process, product design, supply chain system, logistics network etc.
- When any process in applied in a new manner.
- When analyzing the causes of failures, their possible effect and looking up for an optimizing solution that leads to overall improvement in concerned areas.
- When focus is to increase the overall efficiency of any process or whole system.
- Before developing new plans/process, so as to see the possible causes of failure that may occur and their overall impact on various areas.

Every organizations consists of Cross functional teams (CFTs) nowadays, which include expert members from various concerned departments, who uses FMEA process for evaluating various process/design and look for possible causes of failures that can arrive during a process or change in process, their overall impact on various areas and comes up with a proper preventive techniques and steps in order to reduce the intensity of associated risk by eliminating the possible causes of risk. Generally, whenever there occurs a change in process in an organization in any particular area of operation, companies actively uses FMEA tool to detect to what extent the new process can impact the already existing process, what could be the possible causes of failure and how badly they can impact the overall system efficiency. Thus, FMEA helps an organization to modify the process itself or develop a solution to mitigate the risk effect that might occur by adopting a proper risk mitigation strategy in areas of design, manufacturing, supply chain and logistics.

3.1.2 Steps in FMEA

1. First of all, select a system/area/process to analyze. It can include any area of product life cycle like product design, manufacturing, supply chain, and logistics etc.

2. Now, identify the individuals from all departments with specific knowledge and expertise about process, products, and departments and from a cross functional team (CFT) that will brainstorm the modes and causes of failure in concerned areas of inefficiency.
3. Describe the overall process/products in detail to all concerned people involved in process of decision making.
4. Identify all potential possible failures that generally occur or could be. This includes all the system, process, function, components, etc. that could potentially fail to meet the desired standards of quality or essential service requirements, if any.
5. Identify the possible causes of each failure in concerned areas.
6. Identify the potential consequence/effect of this failure on overall system/process or area of concern.
7. Now, assign a severity rating factor (S) to each failure cause as per its impact on overall process. One can rank severity on a rating scale of 1-5 with one being insignificant, two being least significant, 3 being moderately significant, 4 being high significant, and 5 being very highly significant.
8. Identify the possible root causes of each failure. Companies often use various quality tools like Pareto charts, fish bone diagrams (cause and effect diagram), scatter diagrams, etc. to locate potential causes of failure, their intensity of occurrence and overall effect during various processes.
9. Assign each cause on Occurrence rating (O). This is often rated on scale of 1-5 with one being Rare and 5 being Unavoidable.

10. For each potential failure cause, identify the current process control steps/technique that is used by the company in order to prevent the cause of failure and access how effectively it is able to do so.
11. For each control, impart a Detection rating (D) to determine how well the controls are able to detect and control the failure mode, once it is occurred but before a system/process is affected. This can also be rated on likert scale as well with 1 indicating that the current system can detect the problem with absolute certainty and 5 meaning the current system will never be unable to detect the cause of failure.
12. Finally , As per the rankings of product of (S x O x D) for each cause of failure , determine a Risk priority Number (RPN) for draw the potential failure modes diagram for the factors as per the RPN scores obtained in decreasing order.
13. Based on the RPN ratings, plan and implement those essential risk mitigation strategies in concerned areas, so as to address the cause of failure and nullify its overall effect and thereby increasing the system efficiency.
14. Lastly, measure and document the success of each process change and look for revision of the same on regular intervals as per system demand.

3.1.3. FMEA application and findings

For the purpose of finding overall effect of various risks involved using FMEA, a questionnaire was circulated to industrial experts and responses were collected. On the basis of response obtained for various factors involved, an RPN is calculated using formula S*O*D, where

- **Severity** (How severe is the risk)
- **Occurrence** (How often the risk occurs)
- **Detection** (How efficient is the present system in detecting the cause of defect)

PRIORITY	RISK CAUSING FACTORS	RPN SCORES	OVERALL IMPACT
1	Improper Logistics Network	57.62	HIGH RISK
2	Supplier Product Quality	57.45	
3	Inventory Stock Outs	55.83	
4	Inadequacy of Proper M/C , Infrastructure	54.56	
5	Lack of Proper Information Availability	50.37	
6	Factor of Bullwhip Effect	44.98	
7	Excess availability Of Unsold Inventory	42.24	
8	Fluctuation in Raw Material (RM) prices	37.51	MEDIUM RISK
9	Fleet Size , Maintenance requirements & other issues	34.46	
10	Overhead Expenses and Losses	33.37	
11	Buying Power of Supplier	32.62	
12	Limited Facility Size & Capacity	30.38	
13	Product Operational / Manufacturing Cost	30.34	
14	POS Data and Customer Data Mishandling	29.36	
15	Technically Obsolete / Deteroite Inventory	28.51	LOW RISK
16	Exceptionally High/Low Product Pricing	28.12	
17	Supplier Bankrupcy and Available Product Volume	25.38	
18	Improper IT Infrastructure / Cybersecurity	20.48	
19	Facility Location	19.89	
20	Transportation Laws and Other on road charges	18.84	

Figure 3: **FMEA priority chart for various risk causing factors**

From the above FMEA priority risk, Figure 3 obtained on the basis of RPN scores of the risk causing factors responses calculations. From this, we can conclude the following points.

1. Risk Causing Factors like Improper logistics network, Supplier product quality, Inventory stock outs, Inadequacy of proper machine and infrastructure, Lack of proper information availability, Factor of bullwhip effect, and excess availability of unsold inventory are falling under **HIGH RISK** category . The organization has to focus more on these factors, as they highly affect the supply chain efficiency. The organizations need to implement their best practices in place, in order to avoid them and reduce their overall effect on the supply chain efficiency.

2. Risk Causing Factors like Fluctuation in raw material (RM) prices, Fleet size maintenance requirements and other issues, Overhead expenses and losses, Buying power of supplier, Limited facility size and capacity, Product operational/manufacturing cost, POS data and customer data mishandling are falling under **MEDIUM RISK** category. The organization must keep on paying proper attention and control over these factors, as these may turn into higher risk category, if not taken proper control. These factors are as important to focus, as they can hamper the supply chain efficiency to a great extent. The proper strategy and continuous monitoring of such is necessary for maintaining supply chain responsiveness.
3. Risk Causing Factors like Technically obsolete/deteriorate inventory, Exceptionally high/low product pricing, Supplier bankruptcy and available product volume, Improper IT Structure/ Cyber security, Facility location, Transportation laws and other on road charges are falling under **LOW RISK** category . These risk factors are the ones that least affects the supply chain efficiency. The organization need to focus on this on regular intervals to some extent, so as to maintain it in low risk category.
4. The factor, Improper logistics network scores he highest on RPN scores; hence, it should be highly prioritized and taken care off so as to avoid disruptions in the overall supply chain. Also, Supplier product quality and Inventory stock outs too scores almost similar to the highest risk factor and ranked second and third in overall RPN scores. Thus, these too have to be taken proper attention and controlling techniques needed in place to avoid its unseen effects on supply chain efficiency.
5. Transportation Laws and other on road charges is found as the least prioritized risk causing factor with RPN score of 18.84 in order to avoid supply chain disruption. If we consider the highest and least risk causing factor among the main 6 drivers of supply chain, then on the

basis of results, Logistics driver is the most critical risk driver and Facility being the least important driver of supply chain.

6. Therefore, we can consider the Inventory as the best/most important criteria and Facility as the worst/less important among main criteria during calculation for Best-Worst method during our further study.

3.2. Best Worst Method (BWM) Multi Criteria Decision Making

Best worst method (BWM) is one of the most relevant & widely used multi criteria decision making (MCDM) technique introduced by Rezaei (2016). It uses pairwise comparison technique to compare different set of criteria and sub-criteria with respect to given alternatives (Gupta and Barua, 2016). For each set of alternatives, the most (Best) and the least (worst) important criteria are identified and pairwise comparisons are then conducted between the chosen best and worst and other criteria followed, by calculating the optimal weights of criteria and optimal value ξ (Xi).

3.2.1 Steps for implementing BWM approach

1. Determine possible sets of decision criteria. Here we consider criteria (C_1, C_2 …..C_n). For example, in case of buying a mobile the decision criteria can be {C1 (price), C_2 (Storage), C_3 (camera), and C_4 (looks).
2. Classify the most (best) important and least (worst) important criteria from given criteria.
3. Using Pairwise comparison , determine preference of best criteria over other criteria, using 1-9 numbers , The same can be represented as vector (BO)

   $A_B = (a_{b1}, a_{b2}, a_{b3}................................a_{bn})$, where a_{bj} = preference of best criteria B over criteria j and $a_{bb} = 1$.

4. Similarly, determine preference of worst criteria over other criteria , using 1-9 numbers , The same can be represented as vector (WO) :

   $A_w = (a_{w1} , a_{w2} , a_{w3} \ldots\ldots\ldots\ldots a_{wn})^T$

   A_{jw} = preference of criteria j over worst criteria W and $a_{ww} = 1$

5. Now, evaluate the optimal weights of the given criteria (w_1^* , w_2^* , w_3^* …………………w_n^*). The aim is to find the respective optimal weights so as to minimize the maximum absolute difference for *j* in the given set [$\| w_b - a_{bj}w_j \|$, $| w_j - a_{jw}w_w |$]. Converting it into minimax model,

   s.t. minmax [$\| w_b - a_{bj}w_j \|$, $| w_j - a_{jw}w_w |$]

   $\Sigma_j w_j = 1$; $w_j >= 0$ for all j value (1)

   This can also be converted into LP model such that:

   $$\text{Min } \xi^L \text{ wrt} \quad \| w_b - a_{bj}w_j \| <= \xi^L \text{ for all j values;}$$

   $$| w_j - a_{jw}w_w | <= \xi^L \text{ for all j values;}$$

   $$\Sigma_j w_j = 1 \; ; \; w_j >= 0 \qquad (2)$$

6. Finally, by solving the linear equations, find the criteria weights (w_1^*, w_2^*, w_3^*,…, w_n^*) of different alternatives involved in the problem followed by calculation of ξ .

3.2.2. Applying Best Worst method for ranking main risk causing factors

On the Basis of result obtained from FMEA and as per review and literature discussed with automobile industrial experts of different departments, the 6 main criteria that were identified earlier are arranged in the decreasing order of their importance and overall effect, they can cause to the supply chain efficiency and frangibility. The six main drivers or criteria are arranged and the best and worst criteria among them were identified and a multi-criteria decision-making method, the Best Worst Method is applied to get the weightings of each main criterion with respect to the best and worst criteria. Then, the overall optimal weights of each criterion are calculated with respect to the available and worst chosen criteria and finally optimal value **(ξ)** is obtained. The value of **(ξ)** shows to what extent the results are reliable, the closer the Ksi **(ξ)** to zero, the better is the overall consistency.

After finding the best and worst criteria from the available main criteria list i.e. (Price , Transportation, Sourcing, Inventory, Information, and Facility) and on the basis of results obtained from FMEA analysis and expert consensus ; Inventory is identified as the best criteria and Pricing is identified as the Worst criteria among the available main criteria lists . The same has been shown in Table 2 here,

Table 2: Best to Worst (BO) and Others to Worst (OW) comparison for the main criteria

BO	Sourcing(C1)	Information(C2)	Facility(C3)	Inventory(C4)	Transport(C5)	Pricing(C6)
Best Criteria **Inventory(C4)**	**2**	**3**	**5**	**1**	**8**	**6**
OW				Worst Criteria : **Pricing (C6)**		
Sourcing (C1)						**3**
Information(C2)						**5**
Facility(C3)						**6**
Inventory(C4)						**8**
Transport(C5)						**2**
Pricing(C6)						**1**

The following linear equation will be created on the above basis of Equations (1) and (2).

Minimize ξ

$$\xi = C_1 + C_2 + C_3 + C_4 + C_5 + C_6 \tag{3}$$

Subject to equations:

$$C_4 - 2\, C_1 >= 0 \tag{4}$$

$$C_4 - 3\, C_2 >= 0 \tag{5}$$

$C_4 - 5\ C_3 >= 0$ (6)

$C_4 - 8\ C_5 >= 0$ (7)

$C_4 - 6\ C_6 >= 0$ (8)

$C_6 - 3\ C_1 >= 0$ (9)

$C_6 - 5\ C_2 >= 0$ (10)

$C_6 - 6C_3 >= 0$ (11)

$C_6 - 2C_5 >= 0$ (12)

On solving all above Equations (3)-(12) by putting in BWM excel solver, the following criteria weightage value for different criteria say C_1 to C_6,with respect to chosen Best (BO) criteria and Worst (OW) criteria is obtained. Also, the value of KSI (ξ) will be obtained by finding the criteria weightage using BWM excel solver. The Ksi (ξ) Value shows the reliability of results, which will be better if value is near zero.

Table 3: Optimal weightages obtained for the main criteria

Criteria	Weights	KSI (ξ)
Sourcing	0.30150754	
Information	0.201005025	
Facility	0.120603015	**0.30150754**
Inventory	0.301507538	
Transport	0.075376884	
Pricing	0.00070533	

From Table 3, we can infer the obtained weightings of different criteria with respect to BO (best) i.e. Inventory and OW (worst) i.e., Pricing. The Value of KSI (ξ) Obtained here is 0.301 that is close to zero that means the obtained results are reliable and the overall system is highly consistent in nature leading to overall efficiency of supply chain system.

3.2.3. Applying Best Worst method for sub criteria

a. Applying pairwise comparison for Sourcing (C1)

As per the results obtained from FMEA analysis and expert consensus, we have identified **Supplier Quality** as the best criteria and **Supplier Bankruptcy** is identified as the Worst criteria among the available criteria lists under **Sourcing**. The same has been shown in Table 4 here.

Table 4: Pairwise comparison for the Sourcing Factor (C1)

BO	**Supplier quality (S1)**	**Buying power (S2)**	**Supplier Bankruptcy (S3)**	**Supply Fluctuations (S4)**
Best Criteria **Supplier Quality (S1)**	**1**	**8**	**6**	**2**
OW				Worst Criteria : **Supplier Bankruptcy (S3)**
Supplier Quality (S1)				**8**
Buying Power (S2)				**3**
Supplier Bankruptcy (S3)				**1**
Supply Fluctuations (S4)				**5**

The following linear equation will be created on the above basis as shown in Table 4.

Minimize ξ

$$\xi = S_1 + S_2 + S_3 + S_4 \quad (13)$$

Subject to,

$$S_1 - 8\, S_2 >= 0 \quad (14)$$

$$S_1 - 6\, S_3 >= 0 \quad (15)$$

$$S_1 - 2\, S_4 >= 0 \quad (16)$$

$$S_3 - 8\, S_1 >= 0 \quad (17)$$

$$S_3 - 3\, S_2 >= 0 \quad (18)$$

$$S_3 - 5\, S_4 >= 0 \quad (19)$$

By solving the above Equations (13)- (19) in BWM excel solver system, the following criteria weightings for different sub criteria say S_1, S_2, S_3, S_4, with respect to chosen Best (BO) criteria and Worst (OW) criteria under main criteria Sourcing (C1) are obtained . Also, the value of Ksi (ξ) will be generated. The Ksi (ξ) Value shows that the results are reliable.

Table 5: Optimal weightings obtained for the sub-criteria under Sourcing (C1)

Criteria	Weights	Ksi (ξ)
Supplier Quality	0.315789474	
Buying Power	0.315789474	**0.315789474**
Supplier Bankruptcy	0.157894737	
Supply Fluctuations	0.210526316	

Table 5 shows the value of criteria weights for different variables under Sourcing and Ksi (ξ) value which is **0.315789474** that is close to zero that means the obtained results are reliable and the overall Sourcing system is highly consistent in nature leading to overall efficiency of supply chain system .

b) Applying Best worst method pairwise comparison for Information (C2)

As per FMEA analysis and expert consensus, we have identified Information Lacking as the best criteria and Improper IT / Cybersecurity as the Worst criteria among the available sub criteria lists under main criteria Information. The same has been shown in Table 6 here as follows.

Table 6: Pairwise comparison for the Information Factor (C2)

BO	Info. Lacking (I1)	Bullwhip Effect (I2)	POS/ Cust. data Mishandling (I3)	Improper IT/Cyber. (I4)
Best Criteria **Info. Lacking (S1)**	**1**	**2**	**6**	**7**

OW (I4)	Worst Criteria : **Improper IT/Cybersecurity**
Information Lacking (I1)	**5**
Bullwhip Effect (I2)	**8**
POS / Customer data Mishandling (I3)	**3**
Improper IT / Cybersecurity (I4)	**1**

The following linear equation will be created on the above basis,

Minimize ξ

$$\xi = I_1 + I_2 + I_3 + I_4 \tag{20}$$

Subject to,

$$I_1 - 2\, I_2 >= 0 \tag{21}$$

$$I_1 - 6\, I_3 >= 0 \tag{22}$$

$$I_1 - 7\, I_4 >= 0 \tag{23}$$

$$I_4 - 5\, I_1 >= 0 \tag{24}$$

$$I_4 - 8\, I_2 >= 0 \tag{25}$$

$$I_4 - 3\, I_3 >= 0 \tag{26}$$

The following criteria weightings for different sub criteria with respect to chosen Best (BO) criteria and Worst (OW) criteria under main criteria Information (C_2) and the corresponding Ksi (ξ) value is obtained through Equations (20) - (26) using the BWM excel solver.

Table 7: Optimal weightings for the sub criteria under Information (C2)

Criteria	**Weights**	**KSI (ξ)**
Information Lacking	0.492063492	
Bullwhip Effect	0.333333333	**0.174603175**
POS / Customer data Mishandling	0.111111111	
Improper IT / Cybersecurity	0.063492063	

Table 7 shows the value of weights for different criteria and Ksi (ξ) value Obtained that is **0.174603175** for different risk variable under Information main criteria. The obtained value of KSI (ξ) shows that results are reliable and the overall system is efficient.

c) Applying pairwise comparison for Facility (C3)

Now we apply BWM method for our third main criteria, Facility to find out the overall effect and criteria weight of different chosen sub factor variables under it. Based on FMEA results, Inadequate Infrastructure is chosen as the best criteria and Facility Location as the Worst criteria among the available sub criteria lists for Facility**,** main criteria. The same has been shown in Table 8 here as follows.

Table 8: Pairwise comparison for the Facility Factor (C3)

BO	**Facility Size and Capacity (F1)**	**Inadequate Infrastructure (F2)**	**Facility location (F3)**
Best Criteria **Inadequate Infrastructure (F2)**	**3**	**1**	**8**
OW		Worst Criteria : **Facility Location (F3)**	
Facility Size and Capacity (F1)		**4**	
Inadequate Infrastructure (F2)		**7**	
Facility Location (F3)		**1**	

The following linear equations are created on the above basis as shown in Table 8,

Minimize ξ

$$\xi = F_1 + F_2 + F_3 \tag{27}$$

Subject to,

$$F_2 - 3\ F_1 >= 0 \tag{28}$$

$$F_2 - 8\ F_3 >= 0 \tag{29}$$

$F_3 - 4\ F_1 >= 0$ (30)

$F_3 - 7\ F_2 >= 0$ (31)

By using the above Equations (27) - (31) in BWM excel solver, the following criteria weightings for different sub criteria as shown in Table 8, with respect to chosen Best (BO) criteria and Worst (OW) criteria under main criteria Facility (C3) and the desired value of Ksi (ξ) will be calculated. The Ksi (ξ) Value shows the reliability of the obtained results is acceptable.

Table 9: Optimal weightages for the sub criteria under Facility (C3)

Criteria	Weights	KSI (ξ)
Facility Size and Capacity	0.25	
Inadequate Infrastructure	0.66666667	**0.08333333**
Facility Location	0.08333333	

Table 9 shows the value of different criteria weight and the Ksi (ξ) value of **0.08333333** is obtained that is very close to zero that means the obtained results are reliable under case of Facility as the main criteria.

d) Pairwise comparison for Inventory (C4)

Similarly, applying BWM method for our fourth main criteria Inventory to find out criteria weight of different chosen sub factor variables under it, based on FMEA results and expert consensus, Inventory stock outs is chosen as the best criteria and Technically obsolete/ Deteriorate inventory as the worst criteria among the available criteria lists under the main criteria Inventory. The same has been shown in the Table 10 here as follows.

Table 10: Pairwise comparison for the Inventory Factor (C4)

BO	Excess of Unsold Inventory (R1)	Tech. Obs /deteriorate Inv. (R2)	Inv. Stock Outs (R3)
Best Criteria **Inventory Stock Outs (R3)**	**6**	**3**	**1**
OW		Worst Criteria : **Facility Location (R2)**	
Excess of Unsold Inventory (R1)			**4**
Tech Obsolete/deteriorate Inventory (R2)			**1**
Inventory Stock Outs (R3)			**8**

The following linear equation will be created considering Table 10.

Minimize ξ

$$\xi = R_1 + R_2 + R_3 \tag{32}$$

Subject to,

$$R_3 - 6 R_1 >=0 \tag{33}$$

$$R_3 – 3 R_2 >=0 \tag{34}$$

$$R_2 – 4 R_1 >=0 \tag{35}$$

$$R_2 – 8 R_3 >=0 \tag{36}$$

Now, the following criteria weightings and Ksi (ξ) with respect to chosen Best (BO) criteria and Worst (OW) criteria under main criteria Inventory (C4) are obtained using BWM excel solver.

Table 11: Optimal weightings for the sub- criteria under main criteria Inventory (C4)

Criteria	Weights	KSI (ξ)
Excess of unsold Inventory	0.171875	
Tech Obsolete/Deteriorate Inventory	0.125	**0.328125**
Inventory Stock Outs	0.703125	

Table 11 highlights the obtained criteria weights in BWM solver. The value of variables and value of Ksi (ξ) = **0.328125** is obtained for main criteria Inventory. The results indicate the reliability of the overall system for different sub-criteria variables under main criteria Inventory.

e) Pairwise comparison for Transportation (C5)

Now, we have applied BWM method for our fifth main criteria Transportation to find out criteria weight of different chosen sub factor variables under it as per FMEA results and expert consensus; we have chosen Improper Logistics Network as the best criteria and Transportation Laws as the worst criteria among the available sub criteria lists for the main criteria Transportation. The same has been shown in the Table 12 here as follows.

Table 12: Pairwise comparison for the Transportation Factor (C5)

BO	Improper Logistics Network (T1)	Fleet requirements & Issues (T2)	Transportation Laws (T3)
Best Criteria **Improper Logistics (T1)**	**1**	**6**	**9**
OW		Worst Criteria : **Transportation Laws (T3)**	
Improper Logistics Network (T1)			**8**
Fleet requirements & Issues (T2)			**4**
Transportation Laws (T3)			**1**

The following model will be created on the basis of values shown in Table 12,

Minimize ξ

$$\xi = T_1 + T_2 + T_3 \tag{37}$$

Subject to,

$$T_1 - 6\,T_2 >= 0 \tag{38}$$

$$T_1 - 9\,T_3 >= 0 \tag{39}$$

$T_3 - 8\ T_1 >= 0$ (40)

$T_3 - 4\ T_2 >= 0$ (41)

With respect to selected Best (BO) criteria and Worst (OW) criteria under main criteria Transportation (C5), as shown in Table 12 and on the basis of Equations (37) – (41) for main criteria, the following criteria weightings for different sub-criteria will be obtained using BWM excel solver system and the value of Ksi (ξ) is also be obtained. The Ksi (ξ) value show that reliability is in acceptable limits.

Table 13: Optimal weighting for the sub criteria under Transportation (C5)

Criteria	Weights	KSI (ξ)
Improper Logistics Network	0.7692030769	
Fleet requirements & Issues	0.153846154	**0.153846154**
Transportation Laws	0.076923077	

Table 13 shows the following criteria weights of different sub-factors and the obtained Ksi (ξ) value is **0.153846154,** under main criteria Transportation. The results indicate that reliability of the overall system for different sub-criteria variables under main criteria Inventory is high and efficient.

f) Pairwise comparison for Pricing (C6)

Finally, we applied BWM method for our last i.e. sixth main criteria Pricing to find out criteria weight for different chosen sub-factor variables, on basis of FMEA results. We have selected Overhead expenses and losses as the best criteria and Product Manufacturing cost**,** as the worst criteria among the available sub-criteria lists under Pricing as the main criteria. The same has been shown in the Table 14.

Table 14: Pairwise comparison for the Pricing Factor (C6)

BO	High / Low Pricing (P1)	OH expenses & Losses (P2)	Product Manufacturing Cost (P3)
Best Criteria **OH Expenses & Losses (P2)**	**4**	**1**	**6**
OW			Worst Criteria : **High / Low Pricing (P1)**
High / Low Pricing (P1)			**1**
Overhead (OH) Expenses & Losses (P2)			**5**
Product Manufacturing Cost (P3)			**3**

The following linear model can be created based on Table 14.

Minimize ξ

$$\xi = P_1 + P_2 + P_3 \tag{42}$$

Subject to :

$$P_2 - 4 P_1 >= 0 \tag{43}$$

$$P_2 - 6 P_3 >= 0 \tag{44}$$

$$P_1 - 5 P_2 >= 0 \tag{45}$$

$$P_1 - 3 P_3 >= 0 \tag{46}$$

Using Equations (42) - (46) in BWM excel solver, the following criteria weightage for different sub-criteria will be obtained with respect to selected Best (BO) criteria and Worst (OW) criteria under Pricing main criteria (C6)**,** and the value of Ksi (ξ) is obtained once criteria weights are gotten.

Table 15: Optimal weighting for the sub-criteria under Pricing

Criteria	**Weights**	**KSI (ξ)**

High / Low Pricing	0.125	
OH Expenses & Losses	0.71875	**0.21875**
Product Manufacturing Cost	0.15625	

The values of different sub-factors and Ksi (ξ) value, **0.21875 is** obtained under main criteria Pricing, which is as shown in Table 15. The results indicate that reliability of the overall system for different sub criteria variables under main criteria Pricing is satisfactory.

4. Results and discussions

4.1. Findings of the study

In overall the study entitled concludes the following outcomes and understanding.

1. For an efficient and responsive supply chain system, an organization should prioritize all those risk factors which may hamper its overall efficiency. In our study, we have found various risk causing variables under six drivers of supply chain and have prioritized them as per the basis of discussion from industrial experts and research studies on basis of questionnaire using FMEA (Failure mode effect Analysis) method
2. Using FMEA, we have prioritized the various risk causing factors into 3 risk categories namely high, medium, and low risk zones. The Prioritization of all such factors into these risk zones will help organizations to know the overall impact of the variables falling under particular zone and then coming up with a proper mitigation strategy to nullify the overall effect.
3. By prioritizing the risk factors into various zones i.e. high, medium, and low, an organization can form a particular risk mitigation strategy, so as to overcome the effects of that factor on

the business performance and also prioritizing risk factors can also prevent unnecessary efforts from business side, thereby increasing overall system efficiency.

4. Then, using Best worst Method (BWM), an MCDM technique, we have obtained the weightings for various criteria under six main criteria list and then for various sub-criteria that falls under the main criteria. The weightings obtained and the Ksi value (ξ) for each set of criteria and sub-criteria will therefore show the overall importance the criteria and how strongly they can affect the system efficiency, if not taken proper measure to prevent it.
5. The final combined results, as obtained from both FMEA and BWM techniques will allow management to access the nature and overall effect the risk causing factor and their effects on overall system efficiency. Also, it helps to prioritizing them and thus finally coming up with particular risk mitigation strategy against each risk causing factor to improving overall system efficiency.

4.2. Implications of the study for managers

The study holds important learnings for managers/owners of automobile industry sector. The paper has taken into account various number of risk causing factors with respect to different main drivers of supply chain. Using risk priority ranking technique like FMEA, the various risk causing factors under these main risk drivers of supply chain can be ranked on the basis of their overall effect into various risk zones like high, medium, and low risk zones. By identifying to what risk zone the particular factor belong; the managers can come up with a proper risk mitigation strategy needed at place. This will help in reducing the unnecessary effort by introducing a proper approach to mitigate risk and to understand to what extend the resources need to be invested, thereby saving useful production time and cost. Moreover, this will help in detecting the possible reasons of failure that could happen and manager can come up with already available risk controlling techniques before the risk occur in actual.

Secondly, this study involves the use of recent MCDM technique called Best Worst method (BWM) to know about the weightings for each criteria factor with respect to chosen Best and Worst criteria among the available main criteria factors and sub criteria factors, within the main criteria list. The obtained criteria weights of different factors will help managers to know about the impact weighting that a particular risk causing factor can have and to what extent it can affect the overall system. The managers can come up with a required strategy as per the weightings of the risk criteria in overall. Also, the value of Ksi (ξ) obtained during study will show how reliable is the overall system with respect to the chosen risk criteria zone. The value of Ksi (ξ) must be below 1.0 that managers need to maintain for an effective system.

4.3. Limitations and future scope

The major limitation of this is that the study has taken into account the various risk causing factors on basis of 6 main drivers of supply chain. There can be other external and internal risk causing factors, apart from this which could also be included. This can be a direction for future work. Another limitation is there are no relationships considered in between for those sub-criteria falling under different main criteria. This can be also a direction for another future work. Also, future scope may include using various other statistical or data mining techniques to classify the various risk causing variables under different parameters. Also, multivariate analysis or other suitable technique can be applied in order to obtain the relationships between various sub-criteria factors under different main criteria.

5. Conclusions

We have conducted a study on the factors influencing supply chain frangibility and inducing risk considering focus on the Indian automobile industry. A combination of FMEA and BWM techniques were used to prioritize the same. Since, this study is based on feedback and questionnaire responses obtained from industrial experts and audience, who hold good knowledge in various fields of automobile sector. The results obtained for both techniques i.e. FMEA and BWM shows a real current time picture of the overall sector image by highlighting the kind of risk the risk factors, which are then classified into various zones. Thus, practitioners of different firms can took reference from this study and can conduct the analysis to know the overall scenario of their supply chain area. They can also include various other external/internal factors, if any and can make relevant strategies in order to reduce the effects of the risk factors. Thus, practitioners can make their overall system efficient and responsive by using the proposed methodology for risk identification, classification, and prioritization.

Declarations

Ethics approval and consent to participate: The paper has not been submitted or considered for submission elsewhere.

Consent for publication: The author transfer the copyrights to the journal and the publisher, if accepted for publication

Availability of data and material: Data will be made available on request.

Competing interests: No potential conflicts of interests are reported in this research.

Funding: No funding has been received for this research.

References

Araz, O. M., Choi, T. M., Olson, D. L., & Salman, F. S. (2020). Role of analytics for operational risk management in the era of big data. *Decision Sciences*, *51*(6), 1320-1346.

Baksh, A. A., Abbassi, R., Garaniya, V., & Khan, F. (2018). Marine transportation risk assessment using Bayesian Network: Application to Arctic waters. *Ocean Engineering*, *159*, 422-436.

Bello, A. O., Adegun, A., Eze, S. C., ALAO, E. M., & Gbadamosi, B. (2018). Supply chain management: Risk assessment in automotive industry using Fuzzy-AHP model. *International Journal of Mechanical Engineering and Technology*, *9*(12), 552-562.

Cagliano, A. C., De Marco, A., Grimaldi, S., & Rafele, C. (2012). An integrated approach to supply chain risk analysis. *Journal of Risk Research*, *15*(7), 817-840.

Ceryno, P. S., Scavarda, L. F., & Klingebiel, K. (2015). Supply chain risk: empirical research in the automotive industry. *Journal of Risk Research*, *18*(9), 1145-1164.

Chirra, S., & Kumar, D. (2018). Evaluation of supply chain flexibility in automobile industry with fuzzy DEMATEL approach. *Global Journal of Flexible Systems Management*, *19*(4), 305-319.

Choi, T. M., Guo, S., Liu, N., & Shi, X. (2020). Optimal pricing in on-demand-service-platform-operations with hired agents and risk-sensitive customers in the blockchain era. *European Journal of Operational Research*, *284*(3), 1031-1042.

Choi, T. M., Wen, X., Sun, X., & Chung, S. H. (2019). The mean-variance approach for global supply chain risk analysis with air logistics in the blockchain technology era. *Transportation Research Part E: Logistics and Transportation Review*, *127*, 178-191.

Chopra, S., Meindl, P., & Kalra, D. V. (2013). *Supply chain management: strategy, planning, and operation* (Vol. 232). Boston, MA: Pearson.

Elleuch, H., Hachicha, W., & Chabchoub, H. (2014). A combined approach for supply chain risk management: description and application to a real hospital pharmaceutical case study. *Journal of Risk Research*, *17*(5), 641-663.

Gupta, H., & Barua, M. K. (2016). Identifying enablers of technological innovation for Indian MSMEs using best–worst multi criteria decision making method. *Technological Forecasting and Social Change*, *107*, 69-79.

Heidari, S. S., Khanbabaei, M., & Sabzehparvar, M. (2018). A model for supply chain risk management in the automotive industry using fuzzy analytic hierarchy process and fuzzy TOPSIS. *Benchmarking: An International Journal*, *25*(9), 3831-3857.

Helbig, C., Bradshaw, A. M., Wietschel, L., Thorenz, A., & Tuma, A. (2018). Supply risks associated with lithium-ion battery materials. *Journal of Cleaner Production*, *172*, 274-286.

Jerath, K., Kim, S. H., & Swinney, R. (2017). Product quality in a distribution channel with inventory risk. *Marketing Science*, *36*(5), 747-761.

Johnson, K.G., & Khan, M.K. (2003). A study into the use of the process failure mode and effect analysis (PFMEA) in the automotive industry in the UK. *Journal of Material Processing Technology*. *139*, 348-356.

Knobloch, V., Zimmermann, T., & Gößling-Reisemann, S. (2018). From criticality to vulnerability of resource supply: the case of the automobile industry. *Resources, Conservation and Recycling*, *138*, 272-282.

Kumar, M., Basu, P., & Avittathur, B. (2018). Pricing and sourcing strategies for competing retailers in supply chains under disruption risk. *European Journal of Operational Research*, *265*(2), 533-543.

Li, J., & Wang, J. (2019). Comprehensive utilization and environmental risks of coal gangue: A review. *Journal of Cleaner Production*, *239*, 117946.

Liao, G., Li, Z., Du, Z., & Liu, Y. (2019). The heterogeneous interconnections between supply or demand side and oil risks. *Energies*, *12*(11), 2226.

Low, B. K. L., Man, S. S., Chan, A. H. S., & Alabdulkarim, S. (2019). Construction worker risk-taking behavior model with individual and organizational factors. *International Journal of Environmental Research and Public Health*, *16*(8), 1335.

Nurse, J. R., Creese, S., & De Roure, D. (2017). Security risk assessment in Internet of Things systems. *IT professional*, *19*(5), 20-26.

Radivojević, G., & Gajović, V. (2014). Supply chain risk modeling by AHP and Fuzzy AHP methods. *Journal of Risk Research*, *17*(3), 337-352.

Rajesh, R. (2018). Pseudo resilient supply chains: concept, traits, and practices. *Journal of Risk Research*, *21*(10), 1264-1286.

Rezaei, J. (2016). Best-worst multi-criteria decision-making method: Some properties and a linear model. *Omega*, *64*, 126-130.

Rostamzadeh, R., Ghorabaee, M. K., Govindan, K., Esmaeili, A., & Nobar, H. B. K. (2018). Evaluation of sustainable supply chain risk management using an integrated fuzzy TOPSIS-CRITIC approach. *Journal of Cleaner Production*, *175*, 651-669.

Sharma, S.K., & Bhatt, A.K. (2014). Supply chain risk management dimensions in Indian automobile industry. *Benchmarking : An international Journal*, *21* (6), 1023-1040.

Silva, W., Kimura, H., & Sobreiro, V. A. (2017). An analysis of the literature on systemic financial risk: A survey. *Journal of Financial Stability*, *28*, 91-114.

Tan, J., Jiang, G., & Wang, Z. (2019). Evolutionary game model of information sharing behavior in supply chain network with agent-based simulation. *International Journal of Intelligent Information Technologies*, *15*(2), 54-68.

Thöns, S. (2018). On the value of monitoring information for the structural integrity and risk management. *Computer-Aided Civil and Infrastructure Engineering*, *33*(1), 79-94.

Tosun, J. (2017). On the sustained importance of attitudes toward technological risks and benefits in policy studies. *Policy Sciences*, *50*(4), 563-572.

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

Zhong, S., Cheng, R., Jiang, Y., Wang, Z., Larsen, A., & Nielsen, O. A. (2020). Risk-averse optimization of disaster relief facility location and vehicle routing under stochastic demand. *Transportation Research Part E: Logistics and Transportation Review*, *141*, 102015.

Zubarev, S. M. (2020). Legal risks of digitalization of public administration. *Actual Problems of Russian Law*, *15*(6), 23-32.

Figures

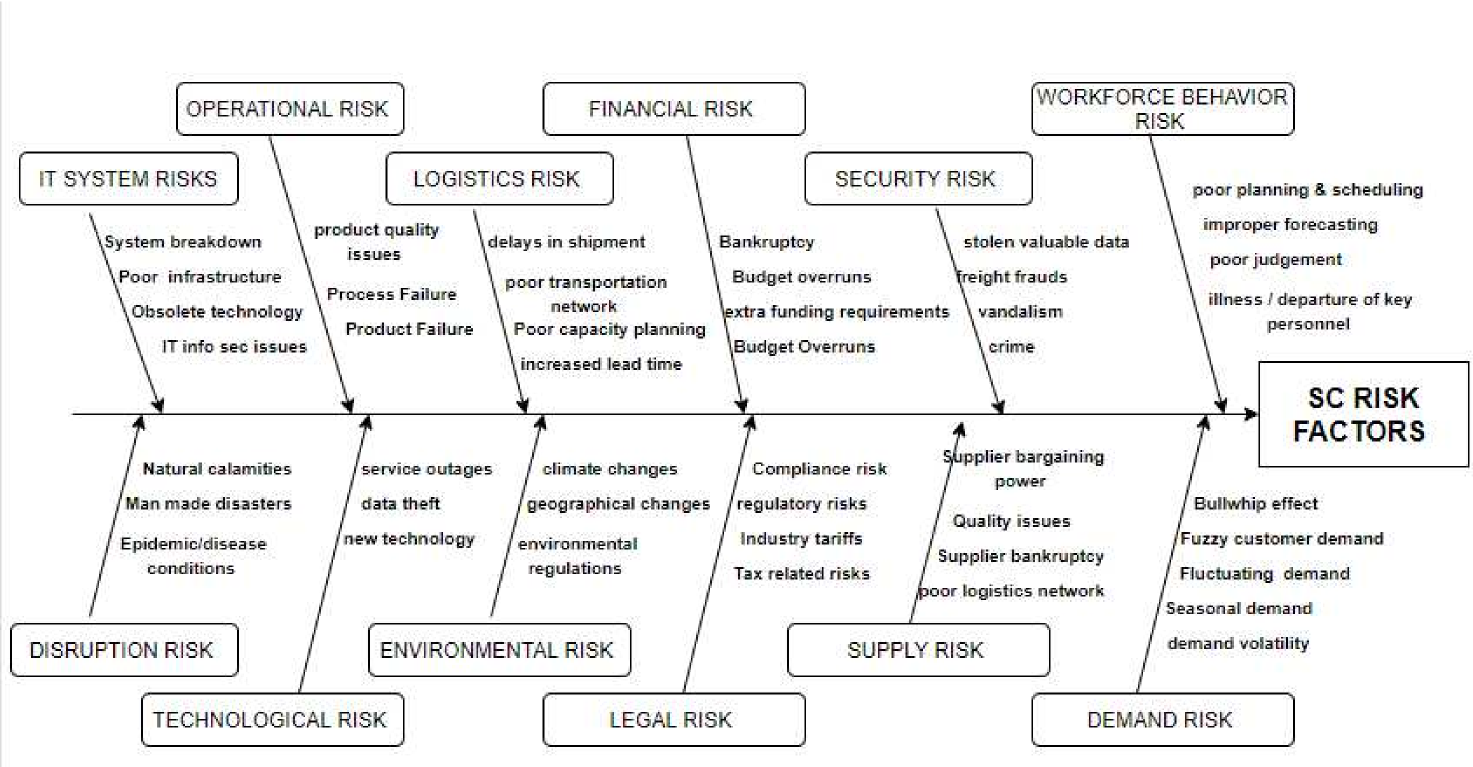

Figure 1

Cause and effect diagram of possible internal and external defects (adapted from Chopra, Meindl, and Kalra, 2013)

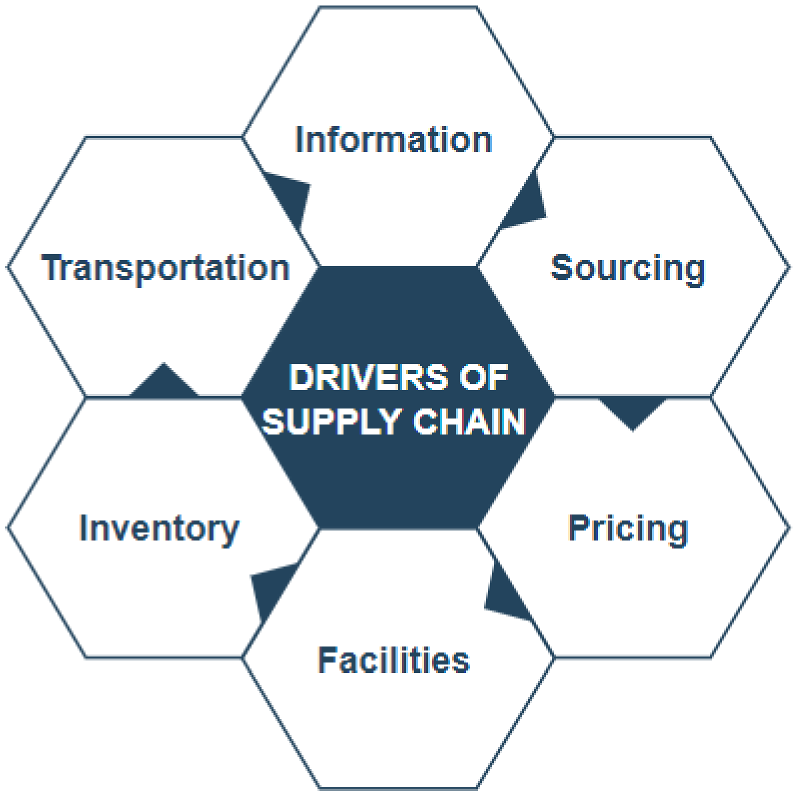

Figure 2

Drivers of supply chain (adapted from Chopra, Meindl, and Kalra, 2013)

PRIORITY	RISK CAUSING FACTORS	RPN SCORES	OVERALL IMPACT
1	Improper Logistics Network	57.62	HIGH RISK
2	Supplier Product Quality	57.45	
3	Inventory Stock Outs	55.83	
4	Inadequacy of Proper M/C , Infrastructure	54.56	
5	Lack of Proper Information Availability	50.37	
6	Factor of Bullwhip Effect	44.98	
7	Excess availability Of Unsold Inventory	42.24	
8	Fluctuation in Raw Material (RM) prices	37.51	MEDIUM RISK
9	Fleet Size , Maintenance requirements & other issues	34.46	
10	Overhead Expenses and Losses	33.37	
11	Buying Power of Supplier	32.62	
12	Limited Facility Size & Capacity	30.38	
13	Product Operational / Manufacturing Cost	30.34	
14	POS Data and Customer Data Mishandling	29.36	
15	Technically Obsolete / Deteroite Inventory	28.51	LOW RISK
16	Exceptionally High/Low Product Pricing	28.12	
17	Supplier Bankrupcy and Available Product Volume	25.38	
18	Improper IT Infrastructure / Cybersecurity	20.48	
19	Facility Location	19.89	
20	Transportation Laws and Other on road charges	18.84	

Figure 3

FMEA priority chart for various risk causing factors