Fuzzy AHP Approach for Supply Chain Strategy Selection : A Post - Pandemic Scenario

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Abstract

Supply chains have been severely disrupted globally due to the COVID-19 pandemic. The paper examined the strategic responses of automobile firms for meeting supply chain challenges they face post-pandemic. Data were collected using a specifically designed structured questionnaire from supply chain experts working with leading automobile manufacturing firms in India. The fuzzy analytic hierarchy process (FAHP), as a part of a multi-criteria decision-making model using R programming, was applied to identify and rank the choice of supply strategies using various criteria, such as lead time, logistics cost (holding cost, carrying cost, warehousing cost, handling cost), and the need of products. Two-wheeler and four-wheeler manufacturing firms were selected for the study. Logistics cost was found to be a dominant criterion, followed by a demand for products and lead time, which helped select an appropriate supply chain strategy. Buffering was observed to be the best strategic choice, and automation and robotics applications were the least preferred ones both for two-wheelers and four-wheeler manufacturing companies. The findings would be helpful to both practitioners and researchers in evaluating diverse strategic choices, especially under the risk and disruptions faced by business firms in the supply chain.

Keywords : **analytic hierarchical process, fuzzy analytic hierarchy process, multi-criteria decision making, supply chain disruption, supply chain risk, logistics cost, multi-sourcing, buffering**

JEL Classification Codes : C60, L62, L91, M11, M16

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In today's global competitive scenario, supply chain management is one of the most significant strategies. Today, the core competency of an enterprise lies in its ability to collaborate and leverage its relationship with supply chain partners in the long run. Global supply chains are practiced by giant companies worldwide. It has become a norm, especially in the last two decades. However, affinity to increase market share by entering new markets, coupled with cutting down costs, their supply chains proved to be very long and difficult to manage. The practice of lean operations has resulted in the risk of disruptions, even with the small margin of error across the chain. In the last two decades, companies have set up manufacturing centers outside their home country, especially where raw materials and labor costs are low. Today, managing the supply chain has become even more complex as

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entities in the supply chain are spread across countries. COVID-19 has disrupted the supply chain leading to segment-wise demand uncertainties or fluctuations, shortages of materials and resources, challenges in managing inventory, and inefficiencies. The impact of the pandemic was not uniform across various communities or sectors of the economy (Mahajan & Chand, 2022). Most sectors globally were exposed to vulnerabilities and fragilities, causing heavy losses and partial or full shutdown of several companies (Lee & Wright, 2020). Harapko (2023) reported that only 2% of companies surveyed were well prepared for the pandemic, and only 11% of the firms, especially in the pharmaceutical or the life sciences sector, reported a favorable outcome. As a major steel consumer, the automotive industry suffered a considerable setback due to the pandemic and lockdown. In countries like India, complete lockdown posed challenges such as not delivering cars on time and less inventory available (Belhadi et al., 2021).

A review of available literature and reports has helped understand supply chain disruptions post-pandemic. However, it was observed that very few studies investigated the impact of the pandemic on supply chains across different industries. Several studies highlighted the strategic options available to companies that could aid in mitigating risk and uncertainties in the post-pandemic supply chain. But the suitability of these options and prioritizing them has not been found in any literature, especially in the Indian context. Indian automobile sector was severely hit due to the pandemic and lockdown. Indian automobile companies are still struggling to sustain and accelerate recovery. A few studies have discussed a set of generic options that minimize supply chain risk and uncertainties. However, choosing the right course of action and prioritizing the supply chain continues to be challenging. Therefore, a detailed investigation of supply chain practices adopted by automobile companies post-pandemic felt necessary. It is important to understand the best strategies that can be adopted by automobile companies leading to the mitigation of uncertainty and risk.

According to Childerhouse et al. (2003), the auto industry has been influential in providing lessons to other sectors because of their accumulated experience in managing supply chain disruptions. Therefore, it was imperative to study the criticality of the supply chain's response in the pandemic-induced disruptions management and to build resilience for the supply chain, especially in the manufacturing sector.

Literature Review

COVID-19 impacted and shocked the global supply chain on three fronts: supply, demand, and logistics (Kumar & Sharma, 2021; Mishra et al., 2022). The automobile sector generates the largest employment among all manufacturing firms in India. However, this pandemic severely hit automotive companies (Accenture, 2020). The automobile industry suffered the most as key manufacturers either shut down following the orders passed by the government or were running with the least staff. Although the nationwide lockdown assisted in limiting the spread of the disease, it adversely affected the value chain of most industries. Dependency on Wuhan, one of the largest hubs for manufacturing auto components, halted supplies of essential components to global automobile manufacturers (Kumar & Managi, 2020; Sharma et al., 2020). Customer demand declined drastically, causing distress among auto manufacturers. Due to reduced purchasing power among customers, a major decline in car sales was observed in many countries. Steel production fell by 1.4% in the first three months of 2020 compared to the same time the previous year (Visiongain, 2022). Managing risk and uncertainty has drawn the attention of various researchers and experts working in this field (Gurtu & Johny, 2021). Various challenges and risks are involved in the supply chain at a global level (Chopra & Sodhi, 2014). The spread of COVID-19 has caused major disruptions concerning the global supply chain (Araz et al., 2020).

Shah (2009) discussed the factors responsible for supply chain performance and suggested alignment of supply chain configuration with business strategy. He also mentioned the need for supply chain agility for improved supply chain performance. When the US faced a terrorist attack in 2011, organizations were compelled to focus on demand and supply uncertainty. Experts started questioning the practice of the JIT (Just-in-Time) system or the concept of lean operations in management. The need for flexibility in the supply chain emerged due to various natural disasters in the past two decades. According to Schmidt and Raman (2012), disruptions were unplanned events that adversely affected a firm's normal operations. Disruptions in suppliers' operations resulted in financial losses to organizations in the past. The LARGE (Lean-Agile-Resilience-Green) paradigm (Carvalho et al., 2011; Cabral et al., 2012) suggested key performance indicators for managing supply chain disruptions as inventory cost, order fulfillment rate, and responsiveness to urgent deliveries. The study observed that an increase in production lead time increased the lead time in delivery of service and the cost associated with it. Lower service level was caused by a decrease in the inventory levels, which negatively impacted resilience and agility in the supply chain. During a slowdown in economic activities, the inventory level went up, increasing obsolescence (Sinha & Dey, 2018). These effects led to a scale-down of processes due to decreased accessibility of working capital.

Despite the rise in individual income, the increase in demand got nullified by supply chain disruptions (Sinha et al., 2020). The study also observed that due to job loss during the pandemic, the income pattern also got changed significantly. Barrios (2020) identified major sources of risks associated with the global supply chain as (a) political and government changes, (b) economic instability, (c) extreme weather events, (d) environmental risks, (e) connectivity, (f) cyber-attacks, (g) poor data integrity and quality, (h) supplier inconsistency, (i) reduced ability to transport goods economically. Ganeshan and Suresh (2017) explored the problems concerning supply chain problems among small and medium enterprises and established the interlinkage of supply chain performance with supply chain strategy. Several authors have researched sustainability in the supply chain. Sharma et al. (2018) suggested a socially responsible supply chain for business performance. Moritz (2020) explained how supply chain disruptions caused by COVID-19 were different from the disruptions faced in the past. Raj et al. (2022) investigated supply chain challenges manufacturing organizations face, particularly in emerging economies, due to the COVID-19 outbreak. They designed a conceptual framework to analyze challenges and suggested pertinent mitigation strategies.

The magnitude of the pandemic has had lasting effects on various aspects of the supply chain, such as (a) redundancy, i.e., possessing additional inventories, low-volume consumption, association with more dealers, etc.; (b) near-shoring enabling the firms to achieve higher efficiencies across supply chains; (c) supply chain resilience through improved perceptibility and periodic supervising of risk. Therefore, it is imperative to rethink existing practices of managing the supply chain and developing more resiliency across the value chain to handle future disruptions (Anbumozhi et al., 2020; Rennie, 2020). Belhadi et al. (2021) identified localization, the use of data-driven and real-time information systems, digital connectivity, supply chain automation, social supply chain focus, and integrated supply chain risk management as the most preferred short-term response strategies by the automobile industry to overcome COVID-19 disruption. In addition, holding extra inventory and creating a reserve capacity are important strategic approaches that minimize disruptions (Lücker et al., 2019; Simchi-Levi et al., 2015).

Shih (2020) pointed out that managers would require first to understand their vulnerabilities (low, medium, or high risks) in respective domains to meet supply chain challenges post-pandemic and then consider taking several options, such as (a) focus on accuracy in demand forecasting through artificial intelligence (AI) power tools to fix cost associated with excessive inventory built up or minimize shortages; (b) switching from single sourcing to multi-sourcing to minimize the risk of disruptions; (c) focus on flexibility in the manufacturing process; (d) diversification of supply base to add more sources in different locations which are not vulnerable to similar risks; (e) determination of buffer or safety stock in case of unavailability of alternate suppliers may result in the risk of obsolescence and inefficient use of capital; (f) process innovations through relocating the supply base and developing a relationship with local suppliers.

Aim of the Study

- To understand risks and uncertainties in managing the supply chain.
- To study strategic responses by automobile firms for meeting the supply chain challenges associated with them post-pandemic.
- To analyze strategic choice preferences for supply chain management among two-wheelers and four-wheelers automobile firms in India post-pandemic.
- To identify the most suitable strategy for managing the supply chain among automobile firms.

Research Methodology

The present study was exploratory cum prescriptive in design and relied on primary and secondary data sources. Secondary sources, such as scholarly articles from journals, magazines, industry reports, etc., were referred to. In addition, literature was reviewed to decipher the sources related to supply chain risks and uncertainties in general and the automobile industry in particular post-COVID-19. For the primary source, data were collected from senior-level executives from 10 different automobile companies responsible for managing the supply chain through specially designed structured questionnaires used in fuzzy AHP (analytic hierarchy process). These companies comprised five each from two-wheelers and four-wheelers manufacturers. The data were collected in February–March 2022. The fuzzy analytic hierarchy process (FAHP), or the multi-criteria decision-making model (MCDM), was applied to the data collected to identify the best strategies to manage the supply chain for these companies.

Multi - Criteria Decision Model and Framework

Based on empirical evidence and literature, dominant supply chain strategic options that lessen uncertainty and disruptions were: (a) demand forecasting accurateness, (b) multi-sourcing, (c) supply base variation, (d) near-shoring, (e) manufacturing elasticity, (f) safeguarding or idleness, and (g) process innovations or automation and robotics applications. A firm (supplier, manufacturer, retailer, distributor, and wholesaler) cannot operate on each strategy, as mentioned earlier, at the same time (Sinha & Dhingra, 2022). Further, a supply chain manager may choose the best among decision alternatives (supply chain strategy) by considering a single criterion: cost, lead time, customer satisfaction, etc. To compare and rank various strategic choices, fuzzy AHP was applied in our study. The analytic hierarchy process (AHP), introduced by Saaty (1987), is a versatile multi-criteria decision-making tool that allows individuals to weigh attributes rationally and evaluate alternatives. The AHP technique has been extensively used in the varied field of managerial decision-making. Rashid and Rokade (2021) used AHP for decision-making in retail service quality. Guru et al. (2021) applied AHP for ranking dimensions for online trust for e-commerce brands. Joshi et al. (2017) identified the key decision area concerning human resource management practices by applying the AHP technique. Multi-criteria decision model was incorporated to determine the best advertising medium (among visual, print, and social media) in the footwear industry (Majeed & Sriram, 2019).

Singh and Nanda (2022) integrated AHP and TOPSIS, the two multi-criteria decision models, to weigh and rank service quality dimensions for fast food restaurant services. Similarly, while making choices among various decision alternatives in the case of a supply chain, the management can choose the most effective supply chain strategy using an optimization model or heuristic approach. AHP is a method of ranking decision alternatives and selecting the best one (Taylor III, 2017). Therefore, using this approach, a numeric score using rating (refer to

Table 1. *Saaty's Rating Scale*

Preference Level	Numeric Value	Reciprocal Value
Equal	1	1
Equal to moderate	2	1/2
Moderate	3	1/3
Moderate to strong	4	1/4
Strong	5	1/5
Strong to very strong	6	1/6
Very strong	7	1/7
Very strong to extremely strong	8	1/8
Extreme	9	1/9

Table 1) is developed in which each decision alternative is ranked, depending upon to what extent the alternative matches the criteria of a decision maker.

FAHP Methodology

A fuzzy analytic hierarchy process was applied to overcome AHP's limitation. It considered uncertainty factors and used a triangular membership function instead of a single definite number, as the traditional AHP methodology used. The triangular fuzzy numbers for pairwise comparison scale and the extent analysis methods for synthetic extents were first introduced by Chang (Chang, 1996), and several researchers have effectively used this approach. A fuzzy AHP approach has been found in earlier works, viz. suppliers' selection (Shaw et al., 2012), supply risk modeling (Radivojević & Gajović, 2014), supply chain risk assessment (Ganguly & Kumar, 2019), prioritization of supply chain disruption management strategies for the petroleum industry (Ghasemzadeh et al., 2017). In fuzzy AHP, a set of linguistic variables (representing triangular numbers) are used to perform pairwise comparisons of both criteria and the alternatives (Kilincci & Onal, 2011). Various criteria were identified for applying the FAHP model in the present research while choosing supply chain strategies. Initially, the structured interview with a group of two experts, each from 10 different car manufacturing (OEM) companies, was conducted to evaluate the criteria. These criteria were lead time, holding cost, carrying cost, warehousing cost, handling cost, and need of products. Further, inventory, transportation, warehousing, and material handling-related costs were clubbed under logistics costs.

The selected experts had several alternatives like demand forecasting accuracy, multi-sourcing, supply base diversification, near-shoring, manufacturing flexibility, buffering/redundancy, and automation and robotics application, as mentioned by Sinha and Dhingra (2022), from which the best one can be chosen. Alternatives like multi-sourcing, supply base diversification, and near-shoring were clubbed under the sourcing strategy. The respondents (supply chain managers) were asked to make a pairwise comparison to indicate a preference for one criterion over the other (or vice versa). This pairwise comparison also indicated how much one criterion was preferred compared to others in the scale defined as per triangular membership function (refer to Table 2). Respondents were asked to make similar pairwise comparisons to indicate a preference for one strategy (decision alternative) over another strategy (decision alternative) under each selected criterion (attribute) using the same scale as mentioned in Table 2. The process followed for applying fuzzy AHP in the current study is shown in Figure 1.

Figure 2 shows the hierarchical structure representing for automobile sector in strategy selection using various decision criteria or attributes.

Table 2. ***Triangular Membership Function***

Categories (Linguistic Terms)	Fuzzy Triangular Scale	Reciprocal Value
Equal importance	1,1,1	1, 1, 1
Intermediate preferences	1,2,3	1/3, 1/2, 1
More important moderately	2, 3, 4	1/4, 1/3, 1/2
Intermediate preferences	3, 4, 5	1/5, 1/4, 1/3
More important strongly	4, 5, 6	1/6, 1/5, 1/4
Intermediate preferences	5, 6, 7	1/7, 1/6, 1/5
More important very strongly	6, 7, 8	1/8, 1/7, 1/6
Intermediate preferences	7, 8, 9	1/9, 1/8, 1/7
More important extremely	8, 9, 9	1/9, 1/9, 1/8

Source : Pouyakian et al. (2022) and Yildirim et al. (2022).

Figure 1. ***Fuzzy AHP Process***

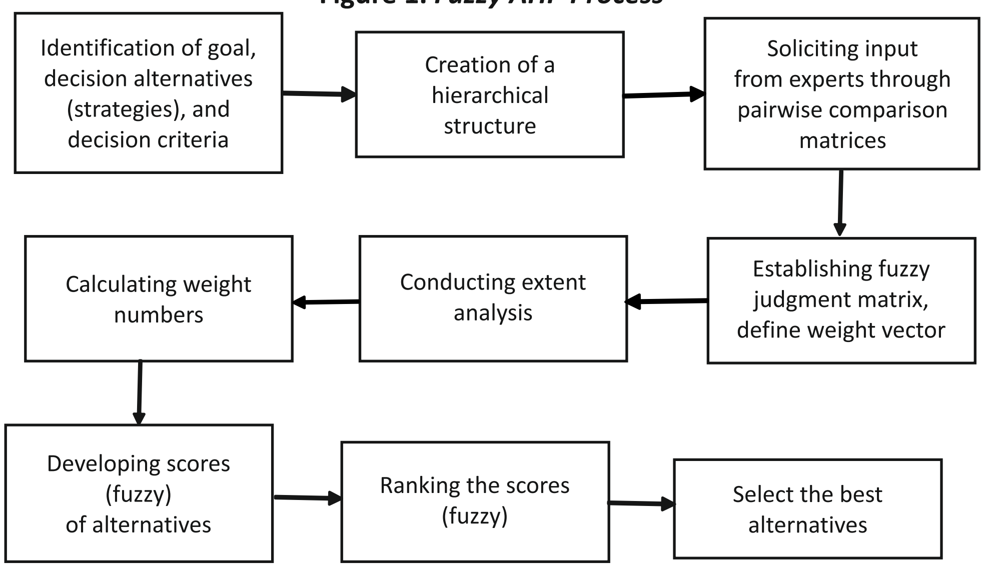
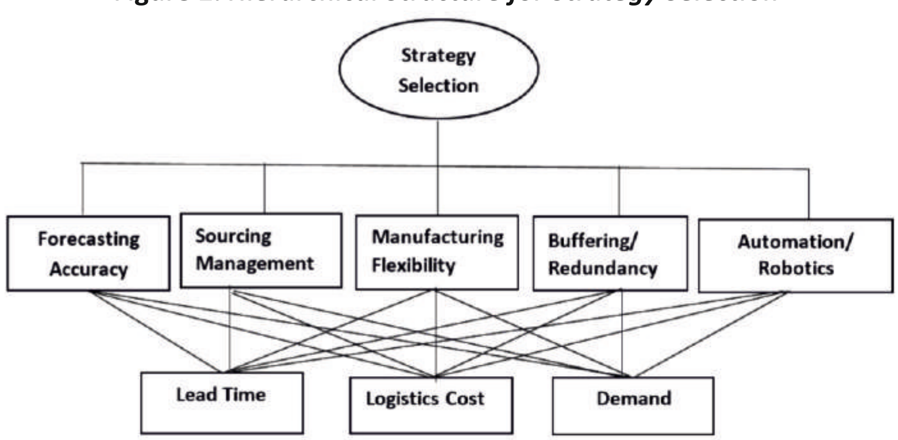


Figure 2. ***Hierarchical Structure for Strategy Selection***



R software was used to run and analyze the FAHP model output. Comparison matrices, developed for supply chain strategy preference under each criterion, were subject to consistency checks before calculating a numeric score for each of these strategies. The consistency of the comparison matrix developed for the criteria was also checked thrice using the consistency ratio defined by Saaty (1987). The output generated by functions in R provides the value of the consistency ratio. Another check is a weak consistency that checks if for *aij*>1 and *ajk*>1 applies that *aik* > = max (*aij, ajk*) for every *i,j,k* =1,2,…,*n*, where *n* is a size of the matrix (Luna et al., 2022). When the matrix passes the test, the functions return TRUE; if it fails, the function returns FALSE followed by printing a short message. The geometric mean of each row of the pairwise comparison matrix represents the weights for criteria.

Model Output and Interpretation

The pairwise comparison matrix output for the fuzzy AHP model for three different decision criteria, i.e., lead time, logistics cost, and demand, is illustrated through tables in subsequent sections. These comparison matrices were checked for consistency before ranking decision alternatives based on the weightage of decision criteria. Decision alternatives, viz forecasting accuracy, sourcing management, manufacturing flexibility, buffering or redundancy, and automation and robotics application, are represented by [1], [2],[3], [4], and [5], respectively, in the matrix. In the case of a pairwise comparison matrix for decision criteria, lead time, logistics cost, and demand are represented by [1], [2], and [3], respectively, in the matrix.

Model Output for Two - Wheeler Companies

Fuzzy Pairwise Matrix of Criteria

A pairwise comparison matrix is designed between each decision criterion viz lead time, logistics cost, and demand using triangular fuzzy numbers. The geometric mean (GM) of fuzzy comparison values for preference of criterion are computed (refer to Table 3) using synthetic extent analysis. The principle of comparison of fuzzy numbers (Mulubrhan et al., 2014) is used for calculating the weight values under each criterion. The weightage for each criterion viz leads time, logistics cost, and demand are 0.225, 0.467, and 0.306, respectively. A consistency ratio of 0.15 < 0.52 indicates enough consistency for correct calculations in the pairwise comparison matrix.

Fuzzy Pairwise Matrix for Decision Alternatives under Criteria 1 (Lead Time)

A pairwise comparison matrix between each decision alternative (strategy), viz forecasting accuracy, sourcing management, manufacturing flexibility, buffering, and automation, is designed using triangular fuzzy numbers.

Table 3. *GM of Fuzzy Comparison Value for Each Criterion*

Criteria	Lead Time	Logistics Cost	Demand
Lead Time	0.305	0.346	0.405
Logistics cost	0.654	0.721	0.822
Demand	0.467	0.480	0.493
Criteria weight	**0.225**	**0.467**	**0.306**
Consistency ratio	**0.15**		

Table 4. ***Fuzzy Comparison Value (Lead Time) : Geometric Mean***

Alternatives	Fuzzy Synthetic Extent Values			Weight for Alternative
Forecasting Accuracy	1.709	1.181	1.912	0.295
Sourcing Management	0.584	0.550	0.522	0.090
Manufacturing Flexibility	2.924	3.301	3.659	0.537
Buffering	0.116	0.137	0.174	0.023
Automation	0.194	0.275	0.522	0.053
Consistency ratio	0.1053			

The geometric mean (GM) of fuzzy comparison values for preference of criterion is computed (refer to Table 4) using synthetic extent analysis.

The consistency ratio is 0.10 < 1.11, so the pairwise comparison matrix is consistent enough for correct calculations. The principle of comparison of fuzzy numbers (Mulubrhan et al., 2014) is used to calculate the relative weight values for each decision alternative. Relative weights under the lead time criterion for each alternative, viz forecasting accuracy, sourcing management, manufacturing flexibility, buffering, and automation, are 0.2955, 0.090, 0.537, 0.023, and 0.053, respectively.

Fuzzy Pairwise Matrix for Decision Alternatives under Criteria 2 (Logistics Cost)

A pairwise comparison matrix between each decision alternative (strategy), viz forecasting accuracy, sourcing management, manufacturing flexibility, buffering, and automation, is made using triangular fuzzy numbers. The geometric mean (GM) of fuzzy comparison values for preference of criterion is obtained (refer to Table 5) using synthetic extent analysis.

The consistency ratio 0.07 < 1.11 indicates that the pairwise comparison matrix is consistent enough for correct calculations. The principle of comparison of fuzzy numbers (Mulubrhan et al., 2014) is used to calculate the relative weight values for each decision alternative. Relative weights under the logistics cost criterion for each alternative, viz forecasting accuracy, sourcing management, manufacturing flexibility, buffering, and automation, are 0.075, 0.023, 0.265, 0.054, and 0.092, respectively.

Fuzzy Pairwise Matrix for Decision Alternatives under Criteria 3 (Demand)

A pairwise comparison matrix between each decision alternative (strategy), viz forecasting accuracy, sourcing management, manufacturing flexibility, buffering, and automation, is made using triangular fuzzy numbers. The

Table 5. ***Fuzzy Comparison Value (Logistics Cost Criterion) : Geometric Mean***

Alternatives	Fuzzy Synthetic Extent Values			Weight for Alternative
Forecasting Accuracy	0.736	0.908	1.100	0.075
Sourcing Management	0.271	0.275	0.302	0.023
Manufacturing Flexibility	2.714	3.301	3.634	0.265
Buffering	6.786	6.603	6.359	0.543
Automation	1.357	1.100	0.908	0.092
Consistency ratio	0.07390			

Table 6. ***Fuzzy Comparison Value (Demand Criterion) : Geometric Mean***

Alternatives	Fuzzy Synthetic Extent Values			Weight for Alternative
Forecasting Accuracy	0.908	1.100	1.357	0.120
Sourcing Management	3.301	3.634	3.684	0.380
Manufacturing Flexibility	0.275	0.302	0.368	0.033
Buffering	2.201	2.725	2.947	0.281
Automation	1.110	1.817	2.221	0.183
Consistency ratio	0.061129			

geometric mean (GM) of fuzzy comparison values for preference of criterion is obtained (refer to Table 6) using synthetic extent analysis.

The consistency ratio 0.06 < 1.11 indicates that the pairwise comparison matrix is consistent enough for correct calculations. Next, the principle of comparison of fuzzy numbers (Mulubrhan et al., 2014) is used to calculate the relative weight values for decision alternatives. Relative weights under the demand criterion for each alternative, viz forecasting accuracy, sourcing management, manufacturing flexibility, buffering, and automation, are 0.120, 0.380, 0.033, 0.281, and 0.183, respectively.

Decision Alternatives Ranking

The relative weight for each decisional alternative under each criterion is shown in Table 7. The calculation of the final weight for each decision alternative followed the two-stage process. First, the weight of the decision alternative is added and then multiplied by the value of the criterion's weight. This results in a final score of 0.138 for forecasting accuracy, 0.147 for sourcing management, 0.255 for manufacturing flexibility, 0.345 for buffering, and 0.111 for automation alternative strategies. The model output for ranking all selected decision alternatives is given in Table 7 and Figure 3.

Rank-wise preferred supply chain strategic options (decision alternatives) for two-wheeler manufacturing companies are observed to be 1st – Buffering; 2nd – Manufacturing flexibility; 3rd– Sourcing management; 4th– Forecasting accuracy; and 5th– Automation and robotics applications.

Table 7. ***Ranking of Decision Alternatives***

Criteria / Alternatives	Lead Time	Logistics Cost	Demand	Final Weight
Forecasting Accuracy	0.295	0.075	0.120	0.138
Sourcing Management	0.090	0.023	0.380	0.147
Manufacturing Flexibility	0.537	0.265	0.033	0.255
Buffering	0.023	0.543	0.281	0.345
Automation	0.053	0.092	0.183	0.111
Weight (Criteria)	0.225	0.467	0.306	

Figure 3. *Ranking of Decision Alternatives (Strategies)*

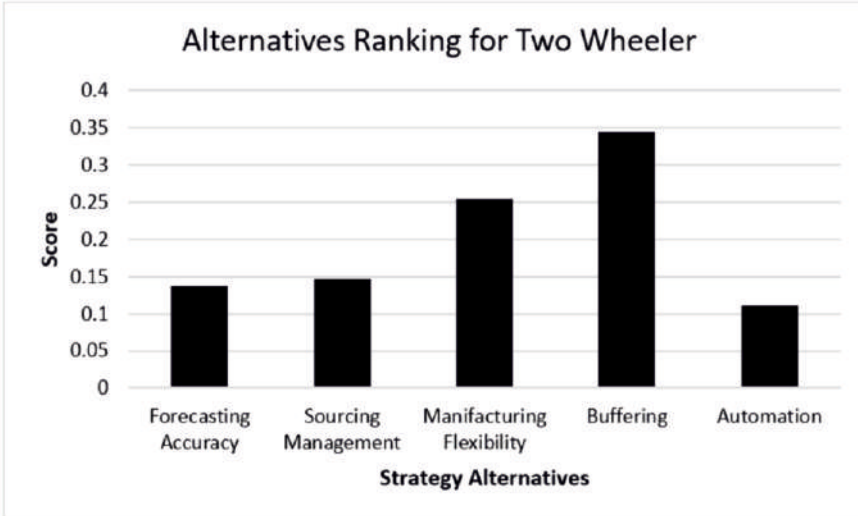


Table 8. *Fuzzy Comparison Value for Each Criterion : Geometric Mean*

Criteria	Lead Time	Logistics Cost	Demand
Lead Time	0.346	0.405	0.5
Logistics cost	0.721	0.822	1.0
Demand	0.480	0.493	0.5
Criteria weight	**0.237**	**0.482**	**0.279**
Consistency ratio	**0.283**		

Model Output for Four - Wheeler Companies

Fuzzy Pairwise Matrix for Decision Criteria

A comparison matrix (pairwise) between each of the decision criteria, viz lead time, logistics cost, and demand, is made using triangular fuzzy numbers. The geometric mean (GM) of fuzzy comparison values for preference of criterion is obtained (Table 8) using synthetic extent analysis.

The principle of comparison of fuzzy numbers (Mulubrhan et al., 2014) is used to calculate the weight values under each criterion. The weightage for each criterion, viz lead time, logistics cost, and demand, are 0.237, 0.482, and 0.279, respectively. The consistency ratio 0.283 < 0.52 indicates the pairwise comparison matrix is consistent enough for correct calculations.

Fuzzy Pairwise Matrix for Decision Alternatives under Criteria 1 (Lead Time)

A pairwise comparison matrix between each decision alternative (strategy), viz forecasting accuracy, sourcing management, manufacturing flexibility, buffering, and automation, is made using triangular fuzzy numbers. The geometric mean (GM) of fuzzy comparison values for preference of criterion is obtained (refer to Table 9) using synthetic extent analysis.

Table 9. ***Fuzzy Comparison Value (Lead Time Criterion) : Geometric Mean***

Alternatives	Fuzzy Synthetic Extent Values			Weight for Alternative
Forecasting Accuracy	1.817	2.289	2.714	0.282
Sourcing Management	1.650	1.310	1.473	0.160
Manufacturing Flexibility	1.6509	1.747	1.842	0.216
Buffering	2.751	2.620	2.578	0.328
Automation	0.091	0.087	0.092	0.011
Consistency ratio	0.867			

The consistency ratio 0.867 < 1.11 shows that the pairwise comparison matrix is consistent enough for correct calculations. The principle of comparison of fuzzy numbers (Mulubrhan et al., 2014) is used to calculate the relative weight values concerning each decision alternative. Relative weights under the lead time criterion for each alternative viz forecasting accuracy, sourcing management, manufacturing flexibility, buffering, and automation are 0.282, 0.160, 0.216, 0.328, and 0.011, respectively.

Fuzzy Pairwise Matrix for Decision Alternatives under Criteria 2 (Logistics Cost)

A pairwise comparison matrix between each decision alternative (strategy), viz forecasting accuracy, sourcing management, manufacturing flexibility, buffering, and automation, is made using triangular fuzzy numbers. The geometric mean (GM) of fuzzy comparison values for preference of criterion is obtained (refer to Table 10) using synthetic extent analysis.

The consistency ratio 0.657 < 1.11 shows that the pairwise comparison matrix is consistent enough for correct calculations. The principle of comparison of fuzzy numbers (Mulubrhan et al., 2014) is used to calculate the relative weight values concerning each decision alternative. Relative weights under the lead time criterion for each alternative viz forecasting accuracy, sourcing management, manufacturing flexibility, buffering, and automation are 0.281, 0.138, 0.233, 0.329, and 0.016, respectively.

Fuzzy Pairwise Matrix for Decision Alternatives under Criteria 3 (Demand)

A pairwise comparison matrix between each decision alternative (strategy), viz forecasting accuracy, sourcing management, manufacturing flexibility, buffering, and automation, is made using triangular fuzzy numbers. The geometric mean (GM) of fuzzy comparison values for preference of criterion is obtained (refer to Table 11) using synthetic extent analysis.

Table 10. ***Fuzzy Comparison Value (Logistics Cost Criterion) : Geometric Mean***

Alternatives	Fuzzy Synthetic Extent Values			Weight for Alternative
Forecasting Accuracy	2.000	2.466	2.884	0.281
Sourcing Management	1.000	1.216	1.386	0.138
Manufacturing Flexibility	2.000	2.027	2.080	0.233
Buffering	3.000	2.838	2.773	0.329
Automation	0.125	0.135	0.173	0.016
Consistency ratio	0.6579			

Table 11. ***Fuzzy Comparison Value (Demand Criterion) : Geometric Mean***

Alternatives	Fuzzy Synthetic Extent Values			Weight for Alternative
Forecasting Accuracy	2.289	2.758	3.174	0.320
Sourcing Management	2.620	2.537	2.519	0.298
Manufacturing Flexibility	0.873	1.087	1.259	0.125
Buffering	1.747	1.812	1.889	0.212
Automation	0.436	0.362	0.314	0.043
Consistency ratio	0.359			

The consistency ratio 0.359 < 1.11 indicates that the pairwise comparison matrix is consistent enough for correct calculations. Next, the principle of comparison of fuzzy numbers (Mulubrhan et al., 2014) is used to calculate the relative weight values of each decision alternative. Relative weights under the lead time criterion for each alternative viz forecasting accuracy, sourcing management, manufacturing flexibility, buffering, and automation are 0.320, 0.298, 0.125, 0.212, and 0.043, respectively.

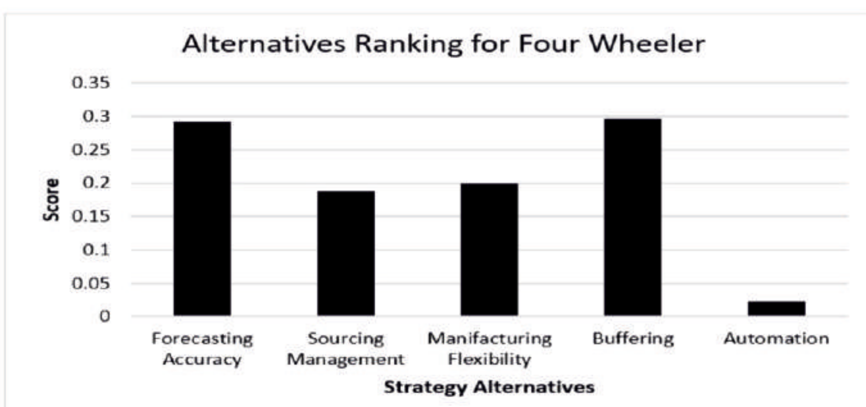
Ranking of Decision Alternatives

The relative weight for each decisional alternative under each criterion is shown in Table 12. Each alternative's

Table 12. ***Ranking of Decision Alternatives (Four-Wheeler)***

Criteria / Alternatives	Lead Time	Logistics Cost	Demand	Final Weight
Forecasting Accuracy	0.282	0.281	0.320	0.292
Sourcing Management	0.160	0.138	0.298	0.188
Manufacturing Flexibility	0.216	0.233	0.125	0.199
Buffering	0.328	0.329	0.212	0.296
Automation	0.11	0.166	0.043	0.022
Weight (Criteria)	0.237	0.482	0.279	

Figure 4. ***Ranking of Decision Alternatives (Strategies)***



weight is added and then multiplied by the weight of the decision criteria. This gives the final weight for each decision alternative, i.e., 0.138 for forecasting accuracy, 0.147 for sourcing management, 0.255 for manufacturing flexibility, 0.345 for buffering, and 0.111 for automation alternative strategies. The model output for ranking all selected decision alternatives is depicted in Table 12 and Figure 4.

Rank-wise preferred supply chain strategic options (decision alternatives) for four-wheeler manufacturing companies are observed to be 1st – Buffering; 2nd – Forecasting accuracy; 3rd –Manufacturing flexibility; 4th – Sourcing management; and 5th – Automation.

Discussion

The study focuses on two types of Indian automotive firms (two-wheelers and four-wheelers). The choice of decision alternatives (SC strategy) and criteria are based on literature and consensus arrived at by the respondents. Logistics cost appears to be a dominant criterion, followed by the demand for products and lead time for strategic supply decisions in both firms. Buffering or redundancy emerges as the most preferred decision alternative, and automation is the least preferred one for both two-wheeler and four-wheeler firms. However, forecasting accuracy ranks 2nd for four-wheelers, while manufacturing flexibility ranks 2nd for two-wheeler firms. The results show that both firms have common strategy preferences when selecting the most and least preferred strategies. As observed, the most preferred strategy of buffering contrasted with the lean manufacturing concept, which was considered one of the best practices, specifically during the last two decades. Forecasting accuracy is the next best strategy for four-wheelers implying that firms must leverage information technology to facilitate real-time information sharing across the supply chain. Appropriate forecasting tools can help in allocating and deploying resources more efficiently.

Regarding two-wheeler manufacturers, manufacturing flexibility as a strategic option can help firms focus on bringing moderate varieties with moderate volumes. This will enable the firm to cater to a mid-range of varieties for a customer without going for large-scale production. Otherwise, they may risk building up inventory and unnecessarily tying up capital. A sourcing strategy is the 3rd and 4th preferred strategic option for 2-wheelers and 4-wheeler manufacturing firms. As leading consulting firms advocate, it implies that companies should not pay too much attention to switching from single to multi-sourcing or offshoring to near-shoring. Instead, they should focus on developing a long-term relationship with the existing suppliers, as the negative impact of the pandemic may not be long-lasting. Finally, automation and robotics applications are the least preferred strategic options. It implies that these technologies require large-scale investment, which may not be feasible for the firms (especially those operating on a medium scale) in the short to medium terms. The focus must be on leveraging the existing technologies. However, in the long run, investment priority will shift to make the firms viable for cutting-edge technology adoption to mitigate negative impacts due to supply chain disruptions.

Further, the present study suggests that the spread of the pandemic forced automakers to rethink JIT policy due to stockouts across the chain. Despite JIT allowing efficient use of inventory, focusing on stockless production and supply, companies need to balance lean manufacturing with buffering strategy in the medium to long term. This may not just help in optimizing resources but also aid in meeting the demand of the customer. While comparing strategies between near-shoring vs. low-cost global sourcing as well as single sourcing vs. multi-sourcing, choices must be made based on both medium and long-term returns rather just short-term goals.

Conclusion

This study discusses the threat and ambiguity in managing the supply chain globally due to the spread of COVID-19. The crisis due to the pandemic has caused structural modifications in the supply chain and consumer behavior. The present study attempts to review the literature published not only in peer-reviewed journals but also referred to reports published by leading consulting firms post-pandemic. This paper focuses on supply chain issues that emerged post-pandemic and explores various strategic alternatives and decision criteria in the automobile sector. A fuzzy analytic hierarchy process (AHP) as a part of the multiple criteria decisions making (MCDM) model is applied to identify the best supply chain strategy for two-wheeler and four-wheeler manufacturing companies to mitigate supply chain risk and disruptions.

Research Implications

Theoretical Implications

The present study presents common and contrasting strategies for two different types of automobile firms. It demonstrates why past and existing practices are critically reviewed and revisited in the dynamic, uncertain, risky global business environment. The study will aid the researchers and practitioners in understanding the rationale and more effective decision-making under risk and uncertainty post-pandemic in supply chain strategy. Mult-criteria decision-making (MCDM) tools like fuzzy AHP can help a researcher evaluate various strategic choices and rank them for effective decision-making for other sectors.

Managerial Implications

The present study can benefit practitioners and managers working in the automobile sector as the results provide the necessary direction for selecting appropriate supply chain strategies and prioritizing strategies based on the multiple criteria in the present to the medium-term scenario. Reshaping of sourcing strategy, exploration of manufacturing substitute materials/components, experimentation with additive manufacturing practices, incremental (if not quantum) adoption of artificial intelligence and robotics in the entire value chain, and leveraging information technology for better supply and demand assessment are some of the key decision areas automotive firms should look forward to. As the current work cuts across the size and scale of firms, management at both middle and senior levels responsible for the supply chain may find it beneficial for decision-making while addressing the risk or uncertainty across the chain in the short-term or medium-term.

Limitations of the Study and Scope for Further Research

The present study discusses the choice of supply chain strategies and criteria situations that emerged post-pandemic. The findings will aid in short-term instead of long-term decision-making. Every decision alternative identified for the study can be further categorized as sub alternative. Pairwise comparison among sub-alternatives can assist in choosing specific strategies by firms. The present study considers three major criteria of decision alternatives. These criteria can be broken into sub-criteria, viz logistics cost can be subdivided into inventory cost, transportation cost, warehouse cost, and material handling cost for further study purposes. The present study did not test the inter-dependence/inter-relationship between criteria and sub-criteria. The analytical network process (ANP) model may be applied in further studies incorporating inter-relationship among criteria and sub-criteria. Future studies can focus on the different types of automobile firms, such as trucks, tractors, etc., pan India. Similar studies can be done for firms operating in steel, textile industries, etc.

Authors' Contribution

Dr. Gyanesh Kumar Sinha conceived the idea and developed a quantitative design and conceptual framework for the empirical study. He conducted the survey and applied R software to do the analysis. Dr. Deepika Dhingra searched the various research papers using keywords from scientific databases like Scopus, Web of Science, etc. and did extensive literature reviews. She identified the research gap and did the proofreading of all the articles. Dr. Nilanjan Chattopadhyay provided the lead contacts for respondents and verified the appropriateness of the research methodology. He also prepared comments for conclusions and practical implications of the study. Finally, Dr. Gyanesh Kumar Sinha wrote the manuscript in consultation with both authors.

Conflict of Interest

The authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript.

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