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AGILITY SUSTAINABLE SUPPLY CHAIN IN AUTOMOBILE INDUSTRY

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Abstract. Automobile industries are facing rapid and unanticipated changes in their business environment. New strategies are needed to remain competitive in the market for those companies. The supply chain plays a crucial role in automobile companies, and improving the supply chain helps them to be successful in the competition. The agile paradigm allows companies to be flexible in the competition, and also sustainable paradigm helps them to popularity among the organizational system. The primary purpose of this study is to combine agile supply chain and sustainable supply chain as one strategy. For this purpose, 73 factors obtained from previous studies and the Fuzzy Delphi Method and Fuzzy Best Worst Method were used to find the best factors and rank them. The results show that 26 elements accepted and after ranking Quality, Supply chain configuration, Customer satisfaction, Suppliers 'green initiatives and Top management vision were the best five factors. In addition, the results confirmed the finding and the new model for an agile sustainable supply chain.

Keywords: agile supply chain, sustainable supply chain, FDM, FBWM, automobile industry.

JEL Classification: L62.

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1. Introduction

Throughout their life cycle, cars are thought to be influenced by the environment in several ways. They utilize a variety of materials, including steel, rubber, glass, and plastic, many of which are costly or difficult to recycle. Moreover, increasing consumption causes air pollution, a deterioration in air quality, and an intensification of the greenhouse effect. The automobile sector has a substantial impact on the environment, the economy, and the structure of society. Therefore, it is crucial for the welfare of society to manage this impact properly in order to reduce it. As a result, car manufacturers have included sustainability metrics into their production procedures (Masoumi et al., 2019). Iran's car output fell dramatically in 2013 as a result of the sanctions imposed on the country due to its nuclear program. Numerous auto parts, particularly those made in France, became scarce as a result of these sanctions. According to Bathaei et al. (2019), as a result, about thirty percent of automakers became insolvent. As a result, the nation's car supply became scarce due to the decrease in production. Certain South Korean companies ceased to supply Korean components to Iran, and PSA Peugeot Citroën was losing money every year as a result of the sanctions that prevented it from selling parts to Iran (Bathaei et al., 2021). Iran responded by stopping the manufacture of a number of international automakers, such as Nissan, Hyundai, and Kia. General Motors, Toyota, and Fiat are among the other impacted businesses. The automotive sector in Iran had an almost 151% growth after Iranian automakers managed to reestablish a connection with European automakers including Peugeot, Citroën, and Renault. Forty international automakers were granted permission to set up shop in Iran during this time (Bathaei et al., 2021).

Nonetheless, due to various constraints and the negative financial situation, Iran's new car production decreased slightly beginning in 2018. The United States' sanctions have resulted in global automakers ending their business operations in Iran, so impeding the flow of autos and auto parts into the country. Consequently, several Iranian automakers have encountered challenges meeting the demands of the market (Soleimani et al., 2018).

There are few systemic studies on these phenomena in the Iranian automotive market, despite the fact that the global automotive market's rapid growth, the environmental influences on it, and the economic effects of international sanctions have all been extensively covered in the scientific literature. However, the majority of the research papers that are now available concentrate on the economic or environmental implications of a project alone. By evaluating the moderating effects of the environment, supply chain flexibility, and geopolitics and economy on Iran's automobile sector, this study aims to resolve this issue.

The primary study topic is whether the Iranian automobile sector has an efficient and adaptable supply chain model. Volatility has recently been exposed by the business as a gaping supply chain model that must defend its stability in the face of callous economic penalties and volatile currency exchange rates, all the while promoting sustainability. These recurring crises that impair production, availability, and financial results cannot be addressed by Iran's current supply chain management procedures.

This kind of research is essential because it enables the examination of economic, environmental, and geopolitical aspects in a particular sector of the Iranian economy. In a way, the goal of this research on the Iranian car industry is to provide additional insight into how other developing nations may persevere in the face of international competition and maintain sustainability. The findings may be helpful for other Iranian sectors and other situations where productivity is hampered by outside factors. Furthermore, the establishment of a versatile and efficient supply chain management system will help Iranian automobile companies thrive in an increasingly competitive global market and promote environmental and economic sustainability.

2. Literature review

2.1. Automotive industry

With a complicated network of suppliers, manufacturers, distributors, and other participants at every stage of the chain, the automotive supply chain is among the biggest and most significant investments made worldwide (Sytch et al., 2022). Because the supply chain system consists of multiple concentric circles of suppliers supplying separate parts, there needs to be the best possible coordination and integration between all the stakeholders in order to minimize delivery cycle times, overhead costs, and quality discrepancies (Üstündağ & Ungan, 2020). However, the repercussions of globalization have stretched the tendency even farther, with automakers now sourcing these parts from other nations. The supply chain is susceptible to political unrest, natural disasters, and other instability because all of the participants are connected and reliant on one another (Umar & Wilson, 2021).

The automotive industry has experienced shorter cycles due to increased rivalry, which emphasizes the importance of supply chain management. Expectations include reducing lead times and adjusting to market swings (Lutz & Bodendorf, 2020). Best practices in supply chain management, such as JIT production, lean manufacturing, and digitization, have been implemented as a result. The practices include supply chain performance measurement, inventory management, and supplier assessment and development (Reyes et al., 2023). But because the automotive supply chain entails interacting with several car suppliers situated across borders, the problems of supplier management, part delivery, and supply quality continue to be a source of worry.

Supply chain management is particularly challenging in the Iranian automotive sector. Iran's vehicle manufacturers have been severely impacted by sanctions, particularly with regard to importing the majority of necessary parts from other nations. Due to this problem and the associated geopolitical risks, the supply chain for Iranian automakers has become more unstable. These include the need to import componentry. Iranian producers have typically looked for one of two outcomes: either they were forced to purchase goods from other nations, sometimes at a premium price, or they attempted to produce inputs domestically (Kelishomi & Nisticò, 2022). Production halts and persistent quality issues are a result of the fact that supply chain risks have not been totally eradicated by these procedures. The Iranian automotive supply chain is another vulnerability cluster that has not yet gotten the attention, connections, or assistance it needs to run efficiently and sustainably (Khalili et al., 2024).

2.2. Automotive business

The need to reduce environmental effect has prompted enterprises to embrace supply chain sustainability. Examining the supply chain's effects on the environment, society, and economy from the point of raw material acquisition to product disposal is known as environmental supply chain management (Taghikhah et al., 2019). Within the automotive sector, this has involved strategies to reduce the use of non-renewable resources, lower greenhouse gas emissions, and promote recycling and responsible consumption. The increasingly strict legislation that have been implemented regionally in an effort to control pollution, as well as the rising community base that is won over by green automobiles, are forcing today's automobile firms to engage in sustainable procurement (Shah et al., 2021). Solutions include using lightweight materials, streamlining the manufacturing process and product life cycle, and increasing the popularity of hybrid and electric vehicles are starting to become standard practice. Life cycle assessment (LCA) techniques currently available provide information about the environmental impact of each product from the point of design to the point of disposal (Iqbal et al., 2020).

The fight to create environmentally friendly automotive supply chain management is still in its infancy, as was mentioned in Iran (Ghasemian Sahebi et al., 2024). All of this has been accomplished without integrating sustainable practices into the requirements for production supply. Nonetheless, social concerns over Iran's environmental dependence on oil have prompted a few Iranian automakers to look for more ecologically friendly solutions, such as reducing pollution, using solar energy and fuel efficiency. However, some of the primary obstacles that skew the sustainability accomplishments of Iran's automakers are economic volatility, including variations in the sanctions regime and supply chain interruptions brought on by them. Favorable policies and encouraging actions from Iran's businesses are required for a sustainable supply chain (Shekarian et al., 2022).

The automobile business is distinguished by a heightened requirement for supply chain flexibility to be efficient, particularly when functioning in a highly dynamic market. Agile supply chains are ones that are put into place with the intention of responding to and adapting to changes in customer demand. Flexibility is a critical success factor in Iran, particularly given the country's unique circumstances, which include supply chain disruptions, currency fluctuations, and international sanctions (Centobelli et al., 2020). Iran's domestic automakers had to use cutting-edge digital tools, such as digital visualizations, to manage supply chain concerns, increase the level of material localization, and broaden their pool of suppliers. However, because supply chain architecture requires a lot of resources, most businesses find it difficult to implement highly flexible and responsive supply chain systems. Maintaining and growing the Iranian automobile sector requires effective management of supply chain flexibility, particularly in light of the country's dynamic political and economic landscape (Valiyan et al., 2023).

Ageron et al. (2012) have presented and expanded upon a theoretical framework known as the Sustainable Supply Chain Management (SSCM) model, which may be implemented to improve the sustainability standards of the Iranian automobile industry (Ageron et al., 2012). Seven fundamental components are identified by this model: benefits and incentives, obstacles and disincentives, supply chain management, justifications, standards, supplier characteristics, and managerial techniques (Matinheikki et al., 2022). The top management's vision, legal and regulatory requirements, market dynamics (Ageron et al., 2012; Giunipero et al., 2012; Gopalakrishnan et al., 2012), customer demand, rivals' strategy (Ageron et al., 2012) and pressure from other stakeholders are some of the factors driving the implementation of SSCM. Quality, price, dependability, service rate, delivery (Ageron et al., 2012), flexibility, certification/accreditation, and partnership/relationship are among the SSCM performance criteria. Reverse logistics, eco-designs, lean management (Ageron et al., 2012), waste minimization, and ISO 14001 certification are a few supply chain "greening" projects (Ageron et al., 2012; Štreimikienė et al., 2024).

Additional elements that account for the implementation of SSCM include supplier characteristics. One could argue that although the first group, which consists of large corporations and strategic suppliers, is more likely to have the resources necessary for sustainability, the second group, which consists of SMEs, might face some challenges (Naradda Gamage et al., 2020). Analyzing the ways in which managerial strategies can minimize obstacles and improve SSCM implementation is crucial. Proactiveness and active, collaborative management styles are needed to address sustainability concerns (Bratt et al., 2021).

Theoretical underpinning and guidelines for supply chain management in the Iranian automotive sectors are provided by combining the SSCM model with the Agile Supply Chain Management model, which Christopher introduced in 2000. Network base factors, market sensitivity (Agarwal et al., 2007), virtual factors, and process integration (Agarwal et al., 2007) are all included in Christopher's approach. The sustainability and adaptability of this integration are crucial for enhancing the productivity and financial stability of Iran's automotive sector. By optimizing partners' skills, functioning at the strategic center of competencies, and boosting market responsiveness and, consequently, coordination, the combined framework ought to improve supply chain performance in response to outside demands and market circumstances (Feizabadi & Alibakhshi, 2022).

2.3. Practical guidance for Iranian manufacturers

Iranian automotive manufacturers can enhance supply chain flexibility and sustainability by learning from successful practices in other industries:

1. *Food and Beverage*: Companies have used real-time data analytics to optimize inventory through just-in-time (JIT) systems, allowing them to respond quickly to consumer demand. Iranian manufacturers can implement similar analytics to align production with market needs.
2. *Textile*: The textile industry has adopted circular economy models, focusing on recycling and eco-friendly materials. Iranian firms should consider partnerships with sustainable suppliers to enhance resilience and reduce waste.
3. *Electronics*: By diversifying supplier networks, electronics companies mitigate risks from disruptions. Iranian manufacturers can similarly expand their supplier base to ensure a steady flow of materials.
4. *Pharmaceutical*: Advanced technologies like blockchain improve transparency and traceability in the pharmaceutical supply chain. Iranian manufacturers could invest in such technologies to enhance operational efficiency and quality control.
5. *Consumer Goods*: Engaging customers in sustainability initiatives has proven beneficial for consumer loyalty. Iranian automotive firms can develop similar programs to boost customer satisfaction and support sustainable practices.

3. Methods and data

The procedure of gathering data is essential to building an accurate model and enhancing the established model's dependability; it calls for careful consideration. A rigorous data collection approach that included two stages was employed for this research investigation. The study focuses on the automotive industry in Iran, with data collected from the years 2017 to 2023, providing a comprehensive overview of the supply chain dynamics during this period.

Initially, information was gathered through two surveys created especially for this research, which were answered by fifty senior expatriates who were specifically chosen from the Iranian auto sector. They all had over ten years of work experience and comprised senior managers, product designers, environmental engineers, and production managers. It was from them that we obtained important information about the main variables influencing SSCM (Sustainable Supply Chain Management) and Agile supply chain. Prior to using the Fuzzy Delphi Method (FDM), participants in the first questionnaire were given detailed information on the factors that SSCM covered. The approach was chosen for this purpose due to its capacity to control the ambiguity and randomness inherent in expert judgments when evaluating them through fuzzy logic. Because FDM was carried out in multiple cycles, it was feasible to outline the strategies for its ongoing improvement and, consequently, to compile the opinions of professionals regarding the identification of all the critical components required for SSCM.

The factors that had been discovered in phase one were ranked using Fuzzy Best-Worst Method (F-BWM) in the second phase. The F-BWM was particularly suitable for assessments where there is a large diversity of criteria and subjective judgment is involved. F-BWM relies on fuzzy logic to provide a selection process that is sensitive to degrees of ambiguity while offering a more flexible and balanced scale for ranking between the best and worst criteria. This approach continuously searches for the precise stance regarding these relative measurements. This strategy made it possible to comprehend the relative importance of each element, which was essential for determining the best course of action for the Iranian car sector going forward. The integration of FDM and F-BWM played a crucial role in ensuring that the values displayed in the final model align with the recognized expert opinion regarding the relative significance of the elements. Additionally, the values are given in a rank-based format that enhances their adaptability.

The choice of FDM and F-BWM over other common methodologies such as Analytical Hierarchy Process (AHP) and TOPSIS was deliberate. While AHP is effective for structuring decision problems and ranking criteria, it struggles with handling the uncertainty and subjectivity present in expert judgments. TOPSIS, on the other hand, is suitable for selecting the best alternative from a finite set of options but does not inherently manage the ambiguity in the experts' assessments. FDM, by integrating fuzzy logic with the Delphi process, allows for a more nuanced consensus-building approach that accommodates the variability in expert opinions. Similarly, F-BWM provides a flexible ranking system that accounts for degrees of uncertainty and gives a balanced weight distribution between the best and worst criteria. These advantages make FDM and F-BWM more appropriate for this study, where dealing with uncertainty and diverse criteria is critical for assessing supply chain factors.

The usage of FDM and F-BWM suggests that there is a lot at risk in supply chain management (SCM), which is a field fraught with uncertainty and challenging to manage, particularly in situations where conditions are complex, as in the case of the Iranian automobile industry. Each of these methodologies offers a structured framework for classifying judgments that are subjective and variable, which are crucial for creating a reliable and practical model. Furthermore, the process of data curation, which included designing the questions and determining the standards for selecting the experts, guaranteed that the information gathered was precise and comprehensive. The present study offers a comprehensive account of the employed methodologies and explicitly specifies that the data collected covers the period from 2017 to 2023 in the Iranian context. Additionally, it highlights several sources of bias and other issues related to generalizability. The aim is to provide additional insights and a robust methodological framework to improve supply chain management practices in the Iranian automotive industry.

The Fuzzy Delphi method process

Fuzzy Delphi Method (FDM) is a statistical technique that integrates the Delphi Method with fuzzy logic to collect and integrate expert opinions in situations of uncertainty. Through the use of fuzzy numbers to depict the opinions of experts, the consensus process is enhanced, so increasing its flexibility in handling ambiguous or inaccurate data (Bathaei et al., 2021).

The FDM contains 5 steps as follow:

Step 1: Interview the experts to determine the importance of the identified variables using the 5-point Linguistic Scale (see Table 1).

Step 2: Convert all the linguistic variables to triangular fuzzy number.

Step 3: Use the vertex method to calculate the average.

Step 4: Defuzzification the weights.

Step 5: The overall group consensus should be more than 70 percent. If the data is found otherwise, Step 2 is executed again as recommended by Cheng and Lin (2002) (Bathaei et al., 2019; Cheng & Lin, 2002).

Table 1. The 5-Point linguistic scale

Linguistic scale	Triangular fuzzy number
Very important	(0.75, 1, 1)
Important	(0.5, 0.75, 1)
Moderately important	(0.25, 0.5, 0.75)
Unimportant	(0, 0.25, 0.5)
Very unimportant	(0, 0, 0.25)

Fuzzy Best-Worst Method

The Fuzzy Best-Worst Method (FBWM) is a variant of the Best-Worst Method that integrates fuzzy set theory to address the intrinsic uncertainty and imprecision in human decision-making. Using pairwise comparisons between the best and worst criteria, represented using fuzzy numbers, it systematically derives the appropriate weights of criteria (Xu et al., 2021). On the other hand, the fuzzy BMW is quite different than FDM. Suppose there are *n* criteria. The fuzzy pairwise comparisons on these *n* criteria can be performed based on the linguistic variables (terms) such as ‘Equally important (EI)’, ‘Weakly important (WI)’, ‘Fairly Important (FI)’, ‘Very important (VI)’, and ‘Absolutely important (AI)’. Table 2 illustrates its respective TFN fuzzy number.

Table 2. A triangular fuzzy number (TFN)

Linguistic terms	Membership function
Equally important (EI)	(1, 1, 1)
Weakly important (WI)	(2/3, 1, 3/2)
Fairly important (FI)	(3/2, 2, 5/2)
Very important (VI)	(5/2, 3, 7/2)
Absolutely important (AI)	(7/2, 4, 9/2)

Then, the fuzzy comparison matrix can be obtained as follows:

$$\tilde{A} = \begin{matrix} & c_1 & c_2 & \cdots & c_n \\ c_1 & \tilde{a}_{11} & \tilde{a}_{12} & \cdots & \tilde{a}_{1n} \\ c_2 & \tilde{a}_{21} & \tilde{a}_{22} & \cdots & \tilde{a}_{2n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ c_n & \tilde{a}_{n1} & \tilde{a}_{n2} & \cdots & \tilde{a}_{nn} \end{matrix}, \quad (1)$$

such that $\tilde{a}_{ij}$ represents the relative fuzzy preference of criterion i to criterion j and $\tilde{a}_{ij}$ = (1, 1, 1) whenever $i = j$.

Generally, a pairwise comparison $\tilde{a}_{ij}$ is defined as a fuzzy reference comparison if i is the best and j is the worst elements, respectively. For $\tilde{A}$, there are totally $2n - 3$ ($n - 2$ Best-to-Others fuzzy comparisons $+n - 2$ Others-to-Worst fuzzy comparisons +1 Best-to-Worst fuzzy comparison) of fuzzy reference comparisons that need to be executed for fuzzy BWM. Both the fuzzy weights of criteria and the fuzzy weights of alternatives with respect to different criteria can be determined by using fuzzy BWM whereby fuzzy weights of alternatives with respect to different criteria are compared against each criterion. Then the fuzzy ranking scores of alternatives can be derived from the fuzzy weights of alternatives with respect to different criteria multiplied by the fuzzy weights of the corresponding criteria. Finally, the crisp ranking scores of alternatives (if need) can be calculated by employing graded mean integration representation (GMIR) method for optimal alternative selection. The procedure is summarized in the following steps.

Step 1. *Build the decision criteria system*. The decision criteria system may consist of n decision criteria (c_1, c_2, ..., c_n).

Step 2. *Determine the best* (*most important*) *criterion and the worst* (*least important*) *criterion*.

Identify the best criterion (c_B) and the worst criterion (c_W) from the system.

Step 3. *Execute the fuzzy reference comparisons for the best criterion.*

The fuzzy reference comparison includes two parts: the pairwise comparison $\tilde{a}_{ij}$ in the case that i is the best element, and here c_i is the best criterion c_B; the other one is the pairwise comparison $\tilde{a}_{ij}$ in the case that j is the worst element, and here c_j is the worst criterion c_W. The first part involves linguistic terms of decision-makers as listed in Table1 earlier and the best criterion over all the criteria can be determined. Then, the obtained fuzzy preferences are transformed to TFNs according to the transformation rules. The obtained fuzzy Best-to-Others vector is:

$$\tilde{A}_B = \left(\tilde{a}_{B1}, \tilde{a}_{B2}, \ldots, \tilde{a}_{Bn}\right), \quad (2)$$

where $\tilde{A}_B$ represents the fuzzy Best-to-Others vector; $\tilde{a}_{Bn}$ represents the fuzzy preference of the best criterion c_B over criterion j , j = 1 , 2 , ⋯, n.

Step 4. *Execute the fuzzy reference comparisons for the worst criterion*. Similarly, the second part involves linguistic terms of decision-makers as listed in Table1 earlier and the worst criterion over all the criteria can be determined. In this step, the other part of fuzzy reference comparison will be done by using the linguistic evaluations of decision makers listed in Table 1. The fuzzy preferences of all the criteria over the worst criterion can be determined. Then, the obtained fuzzy preferences are transformed to TFNs according to the transformation rules. Then, the fuzzy Others-to-Worst vector can be obtained as: $\tilde{A}_W = (\tilde{a}_{1W}, \tilde{a}_{2W}, \ldots, \tilde{a}_{nW})$.

Step 5. *Determine the optimal fuzzy weights* $\left(\tilde{W}_1^*, \tilde{W}_2^*, \ldots, \tilde{W}_n^*\right)$.

The optimal fuzzy weight for each criterion is for each fuzzy pair $\tilde{w}_B / \tilde{w}_j$ and $\tilde{w}_j / \tilde{w}_W$, then $\tilde{w}_B / \tilde{w}_j = \tilde{a}_{Bj}$ and $\tilde{w}_j / \tilde{w}_W = \tilde{a}_{jW}$. To satisfy these conditions for all *j*, a solution should be determined where the maximum absolute gaps of $x\left|\frac{\tilde{w}_B}{\tilde{w}_j} - \tilde{a}_{Bj}\right| and \left|\frac{\tilde{w}_j}{\tilde{w}_W} - \tilde{a}_{jW}\right|$ for all *j* are minimized. It should be noted that $\tilde{w}_B$, $\tilde{w}_j$ and $\tilde{w}_W$ are fuzzy triangular fuzzy numbers. In some cases, we prefer to write $\tilde{w}_j = \left(l_j^w, m_j^w, u_j^w\right)$ for the optimal alternative selection. However, in some cases, we need a crisp value after obtaining fuzzy weight of criterion based on the linguistic variables of decision makers. That is to say, the fuzzy weight $\tilde{w}_j = \left(l_j^w, m_j^w, u_j^w\right)x$ needs to be transformed to a crisp value. This particular arrangement is adopted in this study. The GMIR is employed to transform the fuzzy weight of criterion to its crisp weight. Therefore, the optimal fuzzy weights $\left(\tilde{W}_1^*, \tilde{W}_2^*, \ldots, \tilde{W}_n^*\right)$ is obtained as follows:

$$\text{Min max}_j \left\{ \left| \frac{\tilde{W}_B}{\tilde{W}_j} - \tilde{a}_{Bj} \right|, \left| \frac{\tilde{W}_j}{\tilde{W}_W} - \tilde{a}_{jW} \right| \right\}; \tag{3}$$

$$\text{s.t.} \begin{cases} \sum_{j=1}^{n} R\left(\tilde{W}_j\right) = 1 \\ l_j^w \le m_j^w \le u_j^w, \\ l_j^w \ge 0 \\ j = 1, 2, \ldots, n \end{cases} \tag{4}$$

where $\tilde{w}_B = \left(l_B^w, m_B^w, u_B^w\right)$, $\tilde{w}_j = \left(l_j^w, m_j^w, u_j^w\right)$, $\tilde{w}_W = \left(l_W^w, m_W^w, u_W^w\right)$, $\tilde{a}_{Bj} = \left(l_{Bj}, m_{Bj}, u_{Bj}\right)$,
$\tilde{a}_{Wj} = \left(l_{Wj}, m_{Wj}, u_{Wj}\right)$. (5)

By solving Eq. (5), the optimal fuzzy weights $\left(\tilde{W}_1^*, \tilde{W}_2^*, \ldots, \tilde{W}_n^*\right)$ can be obtained.

Consistency ratio for fuzzy BWM

Consistency ratio (CR) is an important indicator to measure the consistency degree of pairwise comparison. In this section, the CR is proposed for the fuzzy BWM.

A fuzzy comparison is fully consistent when $\tilde{a}_{Bj} \times \tilde{a}_{jW} = \tilde{a}_{BW}$, such that $\tilde{a}_{BW}$, $\tilde{a}_{Bj}$, and $\tilde{a}_{jW}$ are the fuzzy preferences of the best criterion over the worst criterion, the fuzzy preference of the best criterion over the criterion *j*, and the fuzzy preference of the criterion *j* over the worst criterion, respectively. In practice, there may exist inconsistent for criterion *j* related to pairwise comparison. The consistency ratio is employed to check the consistency of the fuzzy pairwise comparison. The CR for fuzzy BWM can be calculated as follows. The maximum possible fuzzy value of $\tilde{a}_{BW}$ is (7/2, 4, 9/2) is corresponds to the linguistic terms 'Absolutely important (AI)' given by decision maker. When $\tilde{a}_{Bj} \times \tilde{a}_{jW} = \tilde{a}_{BW}$, that means $\tilde{a}_{Bj} \times \tilde{a}_{jW}$ may be higher or lower than $\tilde{a}_{BW}$, hence the existence of inconsistency for fuzzy pairwise comparison. When both $\tilde{a}_{Bj}$ and $\tilde{a}_{jW}$ are equal to $\tilde{a}_{BW}$, the inequality is maximum and denoted as $\tilde{\xi}$. The following Equation for $(\tilde{w}_B / \tilde{w}_j) \times (\tilde{w}_j / \tilde{w}_W) = \tilde{w}_B / \tilde{w}_W$ can be obtained as follows:

$$\left(\tilde{a}_{Bj} - \tilde{\xi}\right) * \left(\tilde{a}_{jW} - \tilde{\xi}\right) = \left(\tilde{a}_{BW} + \tilde{\xi}\right). \tag{6}$$

On the other hand, the maximum fuzzy inconsistency $\tilde{a}_{Bj} = \tilde{a}_{jW} = \tilde{a}_{BW}$ can be written as:

$$\left(\tilde{a}_{Bj} - \tilde{\xi}\right) * \left(\tilde{a}_{jW} - \tilde{\xi}\right) = \left(\tilde{a}_{BW} + \tilde{\xi}\right). \tag{7}$$

Then, the following Equation is derived:

$$\tilde{\xi}^2 - \left(1 + 2\tilde{a}_{BW}\right)\tilde{\xi} + \left(\tilde{a}_{BW}^2 + \tilde{a}_{BW}\right) = 0,$$

such that $\tilde{\xi} = \left(l^{\xi}, m^{\xi}, u^{\xi}\right), \tilde{a}_{BW} = \left(l_{BW}, m_{BW}, u_{BW}\right)$.

Further, $\tilde{a}_{BW} = \left(l_{BW}, m_{BW}, u_{BW}\right)$ = (7/2, 4, 9/2) and the maximum value of l_{BW}, m_{BW} and u_{BW} cannot exceed 9/2; i.e. the upper boundary for u_{BW} is used to calculate the consistency index. The value $\tilde{\xi}$ can also be represented as a crisp value ξ. The following Equation is deduced:

$$\xi^2 - \left(1 + 2\tilde{a}_{BW}\right)\xi + \left(u_{BW}^2 - u_{BW}\right) = 0, \tag{8}$$

where u_{BW} = 1, 3/2, 5/2, 7/2, and 9/2, respectively. By solving Eq. (6) for different u_{BW}, the maximum possible ξ can be determined and then used as the consistency index for fuzzy BWM. The obtained consistency index (CI) for fuzzy BWM is listed in Table 3.

Table 3. Consistency index (CI) for fuzzy BWM

Linguistic terms	$\tilde{a}_{BW}$	CI
Equally importance (EI)	(1, 1, 1)	3.00
Weakly important (WI)	(2/3, 1, 3/2)	3.80
Fairly important (FI)	(3/2, 2, 5/2)	5.29
Very important (VI)	(5/2, 3, 7/2)	6.69
Absolutely important (AI)	(7/2, 4, 9/2)	8.04

4. Results and discussions

The Fuzzy Delphi Method (FDM) was employed to evaluate the comprehensive list of 73 factors that impact the sustainable and agile supply chains in the Iranian automotive industry during the study's factor refinement process. This process involved giving each element a fuzzy weight, and only factors with a total score greater than 0 were included. In shows Table 6, seven were further categorized as shows. As a result, 26 of the 73 variables that were thought to be the most important indicators for the particular study were the subject of the final analysis. Table 4 displays these variables, which include some characteristics of both agile and sustainable supply chains, together with the fuzzy weights and the final score following defuzzification. This makes it possible to include the elements that will affect the outcome more precisely and effectively, leading to the creation of a targeted framework for further study and usage in Iran's auto industry.

Additionally, Table 5 presents the recently given codes for the 26 approved criteria in an ordered order determined by the outcomes of the Fuzzy Delphi Method. The acceptable factors are ranked in order of best and worst, and the Fuzzy Best Worst Method (FBWM) will be employed in the subsequent analysis phase. By directly comparing the top and bottom-ranked elements, this sorting makes it possible for the FBWM to assess each one's relative significance within the context of the supply chain and refine it even more.

Table 4. Final FDM weights

Code	Fuzzy numbers (L, M, U)	Final score	Code	Fuzzy numbers (L, M, U)	Final score
A1	(0.53, 0.77, 0.91)	0.73*	E2	(0.43, 0.66, 0.84)	0.64
A2	(0.43, 0.66, 0.84)	0.64	E3	(0.52, 0.76, 0.90)	0.72*
A3	(0.50, 0.75, 0.90)	0.72*	E4	(0.44, 0.67, 0.86)	0.65
A4	(0.52, 0.77, 0.89)	0.73*	E5	(0.46, 0.70, 0.88)	0.68
A5	(0.52, 0.76, 0.90)	0.72*	E6	(0.37, 0.61, 0.82)	0.6
A6	(0.38, 0.61, 0.79)	0.59	E7	(0.43, 0.67, 0.85)	0.65
A7	(0.56, 0.80, 0.93)	0.76*	E8	(0.41, 0.64, 0.82)	0.62
B1	(0.65, 0.90, 0.98)	0.84*	E9	(0.33, 0.57, 0.80)	0.57
B2	(0.52, 0.76, 0.90)	0.72*	E10	(0.36, 0.59, 0.80)	0.58
B3	(0.50, 0.75, 0.90)	0.72*	E11	(0.51, 0.76, 0.90)	0.72*
B4	(0.39, 0.62, 0.79)	0.60	E12	(0.39, 0.62, 0.81)	0.60
B5	(0.43, 0.67, 0.84)	0.65	E13	(0.41, 0.66, 0.84)	0.63
B6	(0.43, 0.66, 0.84)	0.64	E14	(0.36, 0.58, 0.79)	0.57*
B7	(0.33, 0.56, 0.76)	0.55	E15	(0.36, 0.61, 0.83)	0.60
B8	(0.38, 0.61, 0.80)	0.59	E16	(0.42, 0.64, 0.81)	0.62
B9	(0.39, 0.61, 0.80)	0.60	F1	(0.51, 0.75, 0.89)	0.72*
B10	(0.32, 0.55, 0.75)	0.54	F2	(0.51, 0.76, 0.92)	0.73*
B11	(0.45, 0.69, 0.85)	0.66	F3	(0.34, 0.58, 0.78)	0.56
B12	(0.35, 0.57, 0.76)	0.56	F4	(0.47, 0.72, 0.89)	0.69
B13	(0.40, 0.61, 0.80)	0.60	F5	(0.43, 0.68, 0.85)	0.65
B14	(0.40, 0.63, 0.83)	0.62	G1	(0.55, 0.77, 0.89)	0.74*
C1	(0.43, 0.66, 0.84)	0.64	G2	(0.52, 0.77, 0.93)	0.74*
C2	(0.35, 0.57, 0.81)	0.57	G3	(0.52, 0.76, 0.89)	0.72*
C3	(0.43, 0.67, 0.85)	0.65	G4	(0.48, 0.71, 0.90)	0.69
C4	(0.43, 0.67, 0.86)	0.65	H1	(0.53, 0.77, 0.90)	0.73*
C5	(0.52, 0.76, 0.92)	0.73*	H2	(0.42, 0.67, 0.85)	0.64
C6	(0.51, 0.76, 0.92)	0.73*	H3	(0.51, 0.75, 0.90)	0.72*
C7	(0.40, 0.63, 0.83)	0.62	I1	(0.48, 0.72, 0.88)	0.69
C8	(0.41, 0.64, 0.82)	0.62	I2	(0.45, 0.69, 0.88)	0.67
C9	(0.39, 0.63, 0.82)	0.61	I3	(0.39, 0.61, 0.80)	0.60
C10	(0.41, 0.66, 0.86)	0.64	J1	(0.52, 0.76, 0.91)	0.73*
D1	(0.51, 0.76, 0.90)	0.72*	J2	(0.37, 0.61, 0.83)	0.60
D2	(0.51, 0.76, 0.92)	0.73*	J3	(0.50, 0.75, 0.91)	0.72*
D3	(0.38, 0.62, 0.80)	0.60	K1	(0.52, 0.76, 0.93)	0.73*
D4	(0.41, 0.65, 0.82)	0.62	K2	(0.39, 0.63, 0.82)	0.61
D5	(0.37, 0.61, 0.79)	0.59	K3	(0.50, 0.74, 0.92)	0.72*
E1	(0.51, 0.75, 0.88)	0.71*	Total	*26 factors were accepted	

Table 5. New codes for accepted factors

Factor	Old Code	New Code	Weight
Quality	B1	C_B	0.84
Suppliers' green initiatives	A7	C_1	0.76
Supplier's capabilities to innovate	G2	C2	0.74
Customer satisfaction	G1	C3	0.74
Top management vision	A1	C4	0.73
Shared information on real demand	K1	C5	0.73
Eco-design	C5	C6	0.73
Daily P.O.S feedback	H1	C7	0.73
Production resources system	C6	C8	0.73
Strategic suppliers	D2	C9	0.73
Collaborative	F2	C10	0.73
Co-managed inventory	J1	C11	0.73
Customer expectations	A4	C12	0.73
Competitor actions	A5	C13	0.72
Price	B2	C14	0.72
Return on investment	E3	C15	0.72
Large scale companies	D1	C16	0.72
Supply chain configuration	E11	C17	0.72
Trust in suppliers	G3	C18	0.72
Synchronous supply	J3	C19	0.72
Nature of business	A3	C20	0.72
Reliability	B3	C21	0.72
Active	F1	C22	0.72
Listening to customer	H3	C23	0.72
End-to-end visibility	K3	C24	0.72
Financial costs	E1	C_W	0.71

Next, the FBWM is executed as below.

Step 1: Determine the best (most important) criterion and the worst (least important) criterion. The quality and the financial is the best and the worst factors, respectively.

Step 2: Execute the fuzzy reference comparisons for the best criterion. In this step, the quality factor is compared to the other factors based on the 5-point likert scale.

Step 3: Execute the fuzzy reference comparisons for the worst criterion. In this step the other factors are compared to the identified worst factor based on the 5-point likert scale.

Step 4: Determine the optimal fuzzy weights. To obtain the optimal fuzzy weight for each factor, LINGO 17 software is used. For example, equation 9 shows how factor C_B's and C_w's weights are calculated. Table 6 lists the final obtained fuzzy weights such that L = lower, M = middle and U = upper.

Table 6. The final fuzzy weights

Code	Fuzzy weights (l, m, u)
CB	(0.05655,0.06622,0.06666)
C1	(0.0416,0.04499,0.0604)
C2	(0.03912,0.04306,0.04307)
C3	(0.04253,0.053,0.05302)
C4	(0.03853,0.04625,0.04626)
C5	(0.02888,0.03663,0.04217)
C6	(0.03483,0.03955,0.05111)
C7	(0.03585,0.04036,0.05608)
C8	(0.02788,0.03257,0.04216)
C9	(0.02036,0.02038,0.02757)
C10	(0.02571,0.0297,0.03749)
C11	(0.02507,0.02998,0.03128)
C12	(0.02756,0.03211,0.04216)
C13	(0.02953,0.03961,0.03962)
C14	(0.02928,0.02928,0.03367)
C15	(0.03063,0.03645,0.03645)
C16	(0.03409,0.03836,0.04705)
C17	(0.03639,0.04522,0.05447)
C18	(0.03493,0.04036,0.05445)
C19	(0.03719,0.04364,0.05743)
C20	(0.03546,0.04033,0.0543)
C21	(0.03242,0.04623,0.04623)
C22	(0.02869,0.02869,0.04421)
C23	(0.03297,0.03882,0.0515)
C24	(0.02752,0.03213,0.04216)
CW	(0.01484,0.01659,0.01659)

The LINGO 17 is used to transform the fuzzy numbers into crisp values by utilizing Equation 9 below.

$$R\left(\tilde{a}_i\right) = \frac{l_i + 4m_i + u_i}{6}. \quad (9)$$

For example, the weight C_B is calculated as follows:

Fuzzy weight of C_B: (0.05655,0.06622,0.06666),

Final weight C_B: $\frac{0.05655 + 4 * 0.06622 + 0.06666}{6} = 0.06468,$

Fuzzy weight of C_W: (0.01484,0.01659, 0.01659),

Final weight C_W: $\frac{\left(0.01484 + 4 * 0.01659 + 0.01659\right)}{6} = 0.0163.$

The factors and their respective weights are then sorted and shown in Table 7. The Quality factor is the best and important factor for Iranian automobile industry. Moreover, beside Quality, the Customer satisfaction, Suppliers' green initiatives, Supply chain configuration and Top management's vision are the other best factors. The financial cost is the least important factor.

Table 7. Final ranking and weights of factors

Code	Factor	Rank	Weights
CB	Quality	1	0.06468*
C3	Customer satisfaction	2	0.05126*
C1	Suppliers' green initiatives	3	0.04699*
C17	Supply chain configuration	4	0.04529*
C4	Top management vision	5	0.04497*
C19	Synchronous supply	6	0.04486
C21	Reliability	7	0.04393
C2	Supplier's capabilities to innovate	8	0.04241
C7	Daily P.O.S feedback	9	0.04223
C20	Nature of business	10	0.04185
C18	Trust in suppliers	11	0.0418
C6	Eco-design	12	0.04069
C23	Listening to customer	13	0.03996
C16	Large scale companies	14	0.0391
C13	Competitor actions	15	0.03793
C5	Shared information on real demand	16	0.03626
C15	Return on investment	17	0.03548
C8	Production resources system	18	0.03339
C24	End-to-end visibility	19	0.03303
C12	Customer expectations	20	0.03303
C22	Active	21	0.03128
C10	Collaborative	22	0.03033
C14	Price	23	0.03001
C11	Co-managed inventory	24	0.02938
C9	Strategic suppliers	25	0.02158
CW	Financial costs	26	0.0163*

Consistency ratio (CR)

In this section, the Consistency ratio (CR) of the pairwise comparisons of the study are calculated. The unknown value, ξ, is determined using Equation (10) which is the same as the adjustment index. Then, the optimal value of the objective function, $\tilde{\xi}^*$, is calculated. Each model is divided for comparison and plugged into the Consistency index to obtain the incompatibility rate denoted as $\tilde{\xi}^*/\xi$. The closer the Consistency ratio (CR) to zero, the more consistent the comparison is made. The obtained CR value is 0.113 that is an acceptable consistency (see Table 8).

$$\text{Consistency ratio} = \frac{\xi^*}{\text{Consistency index}}. \quad (10)$$

Table 8. Consistency ratio

Consistency ratio (CR)	$\tilde{\xi}^*$	ξ
0.113	0.792	6.966

5. Discussion

The goal of the project is to create a new management philosophy for Iran's automotive industry's sustainable supply chain. Two models serve as the foundation for this new paradigm: the agile supply chain and the sustainable supply chain. Due to a lack of raw materials and other issues with their production line, the Iranian automobile industry has consequently had difficulty providing certain products to the client in the last few years. The supply chain's highest level of development could help businesses remain adaptable in the face of market changes. As far as the authors are aware, this work is the first to suggest combining these two models. As the results show, the five criteria that have the biggest effects on the supply chain in Iran's automobile industry are quality, supply chain configuration, customer satisfaction, suppliers' green activities, and top management's vision.

This integration of agile and sustainable approaches is particularly relevant given the increasing complexity and volatility of the automotive market. By harmonizing these models, the industry can better position itself to respond to disruptions while maintaining a focus on sustainability.

5.1. Environmental concerns

One of the adaptable and long-lasting critical success criteria of supply chain management in the automobile sector is quality. The importance of quality in the supply chain is highlighted by the fact that it influences a wide range of industrial elements. Quality appears to be one of the most important variables connected to the supply chain in Iran's auto industry, according to research (Nosratpour et al., 2018). Additionally, the idea of an agile supply chain emphasizes the significance of quality in guaranteeing adaptability, promptness, and speed in meeting client demands (Suifan et al., 2019). This is corroborated by the fact that an organization's supply chain agility is a function of its flexibility, specifically the quality and speed of its suppliers, which allows it to react quickly to unforeseen circumstances. Furthermore, the question of quality in supply chain agility is raised by the ability of an agile supply chain to quickly respond to a client demand through the caliber of the suppliers and the generation of surplus capacity in resources (Mpuon et al., 2024). Furthermore, the car industry's adoption of an agile supply chain model necessitates increased reactivity, which is directly correlated with the caliber of SC operations (Abdelilah et al., 2023).

To further enhance this adaptability, automotive companies should invest in robust quality management systems and foster a culture of continuous improvement. This investment will not only ensure compliance with industry standards but also position firms to exceed customer expectations in an increasingly competitive landscape.

As a result, green supply chain management, which incorporates the product life cycle approach, is necessary for incorporating environmental considerations into supply chain structure and coordination. This approach is in line with the automotive industry's other sustainable development goal, which is to make sure that environmental considerations are accounted for throughout the product's design, development, production, use, and disposal (Yu et al., 2019). Furthermore, Gopal and Thakkar (2016) support the demand for sustainability in a way that improves customer satisfaction by demonstrating the beneficial relationship between improved supply chain performance and supply chain sustainability in the Indian car sector (Gopal & Thakkar, 2016).

Customer satisfaction is another important factor in the wheel of the automotive supply chain's ability to evolve into a sustainable supply chain. Mishra et al. (2019) emphasize that there is a positive correlation between service quality characteristics and customer happiness, perceived service equity, and perceived service convenience in the automobile maintenance and repair market. This proved that since these factors are essential to the expansion of the automotive supply chain, they must be handled to improve consumer satisfaction (Mishra et al., 2021). Additionally, Rane et al. (2021) found that, when it comes to green efforts, co-operation between suppliers and buyers is quite beneficial. This is demonstrated in the table, which shows that the most popular criterion for greening the supply chain is cooperation with customers for green initiatives (Rane et al., 2021).

To optimize customer satisfaction, automotive firms should actively engage customers in their sustainability efforts, thereby creating a sense of partnership and shared responsibility. This approach not only enhances customer loyalty but also drives innovative solutions in the supply chain.

Businesses now understand that effective management of the green supply chain is crucial to enhancing the overall performance of the automotive sector. This involves integrating environmental considerations into product procurement, manufacturing, end-of-life shipping, and end-of-life management, all of which contribute to maintaining the supply chain's flexibility and sustainability (Kumar et al., 2019). Furthermore, in proving the link between improved supply chain performance in the automobile industry and sustainable supply chain practices, the work by also emphasizes the significance of such endeavors (Fang & Zhang, 2018). Additionally, a thorough framework for choosing green suppliers is provided in the literature by, which extensively expounds on the selection of green suppliers in the automotive industry (Kusi-Sarpong et al., 2023). Based on these findings, it is recommended that green supplier activation be implemented in the automotive industry supply chain in order to improve performance, sustainability, and agility.

Implementing a proactive strategy for selecting green suppliers can yield substantial benefits, including improved supply chain resilience and enhanced brand reputation. It is imperative that automotive companies prioritize this area to align with global sustainability trends and meet consumer expectations for environmentally friendly practices.

5.2. Managerial characteristics

Global automotive supply chain management highlights that the *vision of top management directly influences flexibility and sustainability*. According to Shin et al. (2019), successful partner operation has a negative impact on the overall performance of the supply chain, which emphasizes the need for top management to support reliable partners (Shin et al., 2019). Furthermore, Talukder and Tripathi (2021) identify variations in the supply chain's performance throughout the various segments of the Indian auto industry and emphasize the significance of top management in the development of these performance attributes. A requirement for supply chain management that is sustainable (Talukder & Tripathi, 2021).

The commitment of top management to sustainability initiatives fosters a corporate culture that values transparency and accountability. By prioritizing sustainable practices, management can inspire employees at all levels to embrace these principles, thereby enhancing the organization's overall agility and responsiveness to market changes.

The top management's vision is crucial, as it affects the strategic decisions regarding supplier relationships, investment in sustainable practices, and the adoption of agile supply chain principles. These managerial characteristics directly impact the automotive supply chain's ability to adapt to changing market demands and environmental considerations. A proactive management approach that encourages collaboration with suppliers and customers can help reduce risks and improve supply chain flexibility, especially in a dynamic market like Iran's.

Ultimately, a strategic focus on top management's vision can lead to innovative partnerships and practices that enhance not only operational efficiency but also contribute to the long-term sustainability of the automotive industry. By leveraging collaborative efforts, organizations can better navigate challenges and position themselves for future growth.

6. Conclusions

The present research aims to introduce a new concept for enhancing supply chain management within the Iranian automotive industry through the implementation of agile and sustainable supply chain frameworks. Utilizing the Fuzzy Delphi Method to identify critical factors and the Fuzzy Best-Worst Method to rank and aggregate them, this study addresses fundamental challenges such as raw material scarcity and ongoing supply chain disruptions.

The key factors identified for building this new perspective on sustainable supply chains include *Quality*, *Customer Satisfaction*, *Suppliers' Green Initiatives*, *Supply Chain Configuration*, *and Top Management's Vision*. This paradigm not only systematically extends the literature on the subject but also provides a roadmap for improving the industry's operational fitness. By integrating these factors, the proposed model emphasizes enhancing organizational responsiveness to market demands and improving product quality.

This research is significant as it combines agile and sustainable supply chain strategies, an area previously unexplored in the Iranian automotive context. By offering solutions for agility and sustainability while addressing challenges like material shortages and operational disruptions, this study represents a strategic contribution to the field. It reflects a holistic approach to supply chain management, enhancing sector efficiency and resilience against fluctuations and risks, thus contributing to the sustainable development and competitive advantage of the industry.

The implications of this research are crucial for industry practitioners, providing valuable insights into improving supply chain practices. Managers in the Iranian automotive sector should focus on the identified factors to enhance their supply chain management policies. Achieving these objectives is essential for boosting performance across various organizational levels, emphasizing quality management, appropriate supply chain configurations, customer orientation, climate change management, and alignment with top management's vision. Implementing these elements can help managers mitigate risks, increase adaptability to changing environments, and build stronger supply chains.

Future research should validate the proposed paradigm within the Iranian automotive sector and explore the integration of innovative technologies, such as *blockchain*, *artificial intelligence*, *Internet of Things* (*IoT*), and *digital collaboration platforms*, to enhance supply chain resilience and sustainability. Examining these technologies may reveal methods to improve supply chain relationships and logistics operations.

This study has certain limitations, particularly related to the Fuzzy Delphi and Fuzzy Best-Worst Methods employed as data sources, which may not capture the full complexity of supply chain interactions. Addressing these limitations in future research could involve using additional methodologies or case studies to verify results. Moreover, while this study focuses on the Iranian automotive sector, future research could examine the applicability of the proposed framework to other industries or countries.

In conclusion, this research offers a novel supply chain management framework for the Iranian automotive industry, serving as a springboard for practical changes in supply chain practices and future research on the identified critical factors.

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