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Evaluating Supplier Supply Chain Performance Using a Multi-Criteria Decision-Making Approach: Case Study in the Automotive Industry

Nabil KAYOUH, Btissam DKHISSI

Abdelmalek Essaadi University, National School of Applied Sciences Tetouan, Morocco

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Abstract
Effective supply chain management is essential for business success and continuity. A key component of this management is supplier evaluation, which plays a vital role in mitigating logistical risks, optimizing value, and fostering long-term, mutually beneficial relationships within the supply chain. Although extensive research has been conducted, significant gaps remain in addressing sustainable supply chain risks and integrating them into supplier assessment frameworks. This study addresses this gap by proposing an integrated approach for evaluating and managing supplier-related logistics risks. The approach combines the Best-Worst Method (BWM) to assign relative weights to various sustainable supply chain risks with the fuzzy TOPSIS method to rank suppliers based on their risk profiles. A focus group is used to identify appropriate strategies to mitigate the identified risks. To demonstrate the practicality and effectiveness of the proposed framework, a real-world case study involving a multinational automotive company is presented. The results indicate that two specific suppliers require immediate attention and targeted risk mitigation strategies. This research provides supply chain managers with a robust evaluation methodology and actionable insights for improving supplier risk management in the automotive sector.

Keywords
Supply chain risk management, multi-criteria decision making, best-worst method, fuzzy TOPSIS, supplier evaluation, industry.

Introduction

In today's dynamic and increasingly globalized marketplace, the success and long-term sustainability of companies are closely tied to the efficient management of their supply chains. Modern supply chains are no longer viewed solely as logistical networks but are recognized as strategic assets that can offer significant competitive advantages. As organizations face mounting challenges – including economic volatility, geopolitical instability, technological disruptions, and environmental changes – the capacity to effectively manage supply chain risks has become critically important (Khojasteh-Ghamari, s.d.) The complexity of contemporary supply chains has intensified, requiring companies to address these risks while simultaneously maintaining cost-efficiency, quality standards, and delivery performance.

***Corresponding author**: Nabil Kayouh – Abdelmalek Essaadi University, National School of Applied Sciences, Tetouan, phone: (+212) 674398639, e-mail: nabil.kayouh@etu.uae.ac.ma*

Supply chain risks are multifaceted, encompassing a wide range of uncertainties that may affect organizational operations – ranging from material shortages and supplier failures to geopolitical instability and climate change. Although these risks are increasingly recognized, a gap persists in the academic literature regarding comprehensive methodologies that integrate risk assessment with supplier selection and performance evaluation. Existing research often addresses isolated risk factors, with limited focus on the integration of multiple, interrelated risks that can significantly impact supply chain resilience (Güneri & Deveci, 2023).

For example, the bankruptcy of the major automotive interiors supplier Collins & Aikman resulted in an estimated $665 million in losses for its customers, illustrating the substantial financial consequences of supplier failure (Gernert et al., 2023). Similarly, the bankruptcy of Delphi led General Motors to incur costs exceeding $10.6 billion, emphasizing the potential for severe financial and operational disruptions resulting from supplier insolvency (Gernert et al., 2023). Additionally, the COVID-19 pandemic caused widespread disruptions in global supply chains, with nearly 90% of manufacturing firms in Germany experiencing production halts due to supply shortages

(*Podcast Series*, s.d.) Volkswagen's production lines, for instance, were significantly affected as Chinese suppliers struggled to deliver critical components such as semiconductors and batteries, further demonstrating the risks associated with global supply chain dependencies (Wissuwa et al., 2022).

These incidents underscore the urgent need for more sophisticated and holistic approaches to supplier evaluation and supply chain risk management. Effective evaluation extends beyond cost considerations and involves identifying and mitigating the diverse risks associated with suppliers. However, traditional methods frequently fall short in addressing the full spectrum of risks, especially when these risks are interdependent and necessitate complex decision-making processes.

Recent studies have highlighted the importance of considering not only economic aspects but also social, environmental, and geopolitical dimensions of supply risks (Wu et al., 2023). Overlooking these factors can lead to reputational damage and the loss of opportunities for strategic collaboration with suppliers. As supply chains become increasingly global and diverse, the integration of sustainability and ethical considerations into the supplier evaluation process has become essential (Ali & Zhang, 2023). For instance, manufacturing firms are under mounting pressure to comply with stringent environmental regulations and to reduce their carbon footprints – factors that increasingly influence supplier selection criteria.

Earlier studies have introduced various decision-support approaches and procedures (Karamoozian & Hong, 2023) .While several models have been proposed for supplier selection, relatively few have integrated a multi-criteria decision-making (MCDM) approach that considers both the risks associated with suppliers and their adherence to sustainable practices. The present study addresses this gap by proposing a comprehensive framework that combines the Best-Worst Method (BWM) and fuzzy TOPSIS to evaluate suppliers across multiple risk dimensions. This integrated approach enables the relative importance of diverse risks – economic, environmental, social, and others – to be assessed, thereby facilitating a more holistic evaluation of supplier performance and risk exposure.

The highly competitive and demanding nature of the automotive industry has driven the sector to continuously enhance supply chain performance. As a major contributor to the global economy, the industry produces over 95 million vehicles annually worldwide (Karamoozian et al., 2024).

The automotive industry, with its extensive and intricate supply networks, is particularly vulnerable to risks arising from supplier disruptions. This sector is characterized by a complex network of suppliers, manufacturers, wholesalers, and distributors, all interdependent for materials, components, and logistics (Chen et al., 2016). Given this complexity, it is essential for companies in the automotive industry to implement robust supplier evaluation mechanisms that extend beyond cost assessment to encompass a comprehensive evaluation of potential risks. Regular performance assessments of suppliers are necessary to identify those at risk and to develop mitigation strategies before such risks escalate.

In Morocco, the automotive industry is primarily concentrated in three major cities with dedicated free zones: Tangier, Kenitra, and Casablanca, as illustrated in Figure 1.

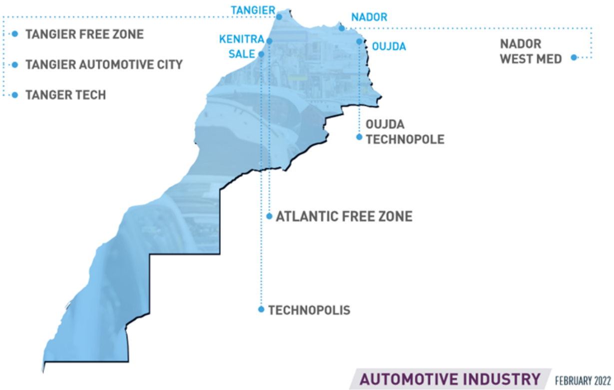

Fig. 1. Automotive free zones in Morocco

This paper presents a novel approach that integrates two well-established methodologies – Best-Worst Method (BWM) and fuzzy TOPSIS – to evaluate suppliers based on their risk profiles. The application of this approach within a real-world automotive parts manufacturer demonstrates its practical utility and potential to enhance supplier selection and risk management processes. The objective is to offer both a methodological contribution to the academic literature and actionable insights for supply chain managers navigating increasing complexities in decision-making.

The remainder of the paper is organized as follows: Section 2 provides a comprehensive review of the existing literature on supply chain risks, supplier evaluation, and decision-making methodologies, including the Best-Worst Method (BWM) and fuzzy TOPSIS. Section 3 details the methodology, describing the steps involved in implementing the proposed framework. Section 4 presents the results of applying the model within a real-world automotive company, highlighting key findings and practical implications. Finally, Section 5 concludes the paper and outlines directions for future research.

Literature review

To achieve the objectives of the proposed methodology, an in-depth review of the existing literature was conducted. The first section addresses logistical risks with a focus on sustainability considerations. The second section discusses supplier assessment within supply chains. The third and fourth sections detail the procedural steps of the Best-Worst Method and fuzzy TOPSIS methodologies, respectively. Finally, strategies for mitigating inbound supply chain risks identified in the literature are presented.

Part 1: Inbound sustainable supply chain risks

One of the most critical phases in supply chain risk management (SCRM) is the identification of risks and failure modes. Most previous studies have classified risks into two broad categories: internal or external to the supply chain. Other studies have further categorized risks as upstream, operational, or downstream within the supply chain.

The present literature review focuses primarily on upstream risks, with particular attention to sustainability aspects, including social, economic, and environmental dimensions.

To identify inbound risk factors, a new typology of risk and sub-risk classifications has been proposed. The main clusters identified include economic, quality, logistical, environmental, social and security, cooperation and collaboration, technical, organizational, legal, and institutional risks.

Regarding economic risk factors, several elements have been identified as having a significant impact on supply chain performance. A high risk of supplier bankruptcy and poor financial stability are considered major concerns, as highlighted by (Gernert et al., 2023; Kao, 2022; Ruiz-Torres et al., 2022). Additionally, cost evaluation risk has been recognized as a threat to supply chain continuity Wu et al., 2023; Chen et al., 2016). Other relevant factors include cash flow instability (Chen et al., 2016) and an unfavorable local economic environment (Tong et al., 2022). (Ahmadi et al., 2023) further emphasized risks such as the unavailability of financial resources to support innovation, insufficient sustainability value delivered to customers, and inadequate funding for research and development activities.

Controlling quality risk factors is crucial in supply chains. The delivery of poor-quality products is identified as one of the most significant risks according to several studies (Güneri & Deveci, 2023; Wu et al., 2023; Chen et al., 2016; Tong et al., 2022; Cagnin et al., 2016; Coşkun et al., 2022). Issues related to suppliers' quality management systems may also impact customers' production processes, depending on specific customer requirements (Coşkun et al., 2022; Sahu et al., 2023). Additionally, poor handling of grievances and complaints by suppliers has been highlighted as a critical risk factor in the literature (Wu et al., 2023; Depczyński, 2021; Sahu et al., 2023).

Logistical risk factors are among the most extensively discussed in the literature, as they directly affect supplier performance and customer production. High delivery risk and inadequate delivery conditions have been noted by multiple authors (Wu et al., 2023; Chen et al., 2016; Tong et al., 2022; Utama et al., 2022; Depczyński, 2021; Coşkun et al., 2022; Sahu et al., 2023). Transportation failures and associated risks are also frequently mentioned (Wu et al., 2023; Sahu et al., 2023). Capacity risk has been identified by several researchers (Cagnin et al., 2016; Kao, 2022; Sahu et al., 2023), including factors such as overproduction or overshipment, response service rate to customers, demand visibility and web integration issues, adaptability to demand and supply changes, order processing efficiency, supplier sourcing capability, and flexibility related to warehouse location.

In today's environment, the application of sustainable energy practices is critical (Karamoozian & Zhang, 2025). Given the increasing environmental awareness among the public and the enforcement of stringent government regulations, manufacturing organizations must address emerging ecological considerations to ensure long-term viability in the global market (Ali & Zhang, 2023).

Numerous studies have identified environmental risk factors that may impact supply chain continuity. These include the lack of green product design (Kao, 2022; Tong et al., 2022; Lo, 2023; Bonab et al., 2023), poor pollution control and gas emissions (Wu et al., 2023; Ali & Zhang, 2023; Bonab et al., 2023), risks associated with reuse and recycling (Wu et al., 2023; Lo, 2023; Bonab et al., 2023), non-compliance with environmental regulations (Wu et al., 2023; Chen et al., 2016; Tong et al., 2022; Cagnin et al., 2016; Baki, 2021; Sahu et al., 2023), low utilization of renewable energy (Lo, 2023), and issues with environmental management systems (Kao, 2022; Coşkun et al., 2022; Bonab et al., 2023).

A third aspect of sustainability is social and security risk factors, (Wu et al., 2023; Chen et al., 2016; Cagnin et al., 2016; Lo, 2023) confirmed that safety risk can be harmful to the continuity of supply chains, social risk (issue in social management systems) is also mentioned by (Cagnin et al., 2016; Lo, 2023; Baki, 2021); Competency risk (employees capability and absence of training facilities and training supports) are also very important according to (Güneri & Deveci, 2023; Kao, 2022; Lo, 2023; Baki, 2021; Sahu et al., 2023), Human and labor rights risk (Chen et al., 2016; Coşkun et al., 2022), non-respect of corporate social governance & compliance (Kao, 2022; Coşkun et al., 2022); and finally bad conflict/problem-solving capability (Kao, 2022).

A third dimension of sustainability involves social and security risk factors. Several studies have confirmed that safety risks can negatively affect the continuity of supply chains (Wu et al., 2023; Chen et al., 2016; Cagnin et al., 2016; Lo, 2023). Social risks, including issues related to social management systems, have also been highlighted (Cagnin et al., 2016; Lo, 2023; Baki, 2021). Competency risks, such as employees' capabilities and the lack of training facilities and support, are considered critical factors in supply chain resilience (Güneri & Deveci, 2023; Kao, 2022; Lo, 2023; Baki, 2021; Sahu et al., 2023).

Moreover, risks related to human and labor rights (Chen et al., 2016; Coşkun et al., 2022), noncompliance with corporate social governance standards (Kao, 2022; Coşkun et al., 2022), and poor conflict or problem-solving capabilities (Kao, 2022) have been identified as potential threats to sustainable supply chain management.

Cooperation and collaboration between suppliers and customers are critical for overall business continuity. Numerous studies have highlighted this aspect. For instance, (Tong et al., 2022) identified risks related to poor bargaining power. Other researchers have pointed out the lack of external communication agility (Depczyński, 2021; Sahu et al., 2023); and insufficient integration with customer services (Sahu et al., 2023); Additionally, issues concerning attitude, trust, and transparency in sharing real-time information have been emphasized (Kao, 2022; Lo, 2023; Sahu et al., 2023). Poor relationship closeness (Kao, 2022) and inadequate assessment of previous cooperation efforts (Depczyński, 2021) have also been recognized as risk factors affecting the effectiveness of supplier-customer collaboration.

Sahu et al., (2023) identified several important technical risk factors, including the effectiveness of manufacturing processes, information flow mechanisms, cultural product improvement, the extent of online solutions, and technological plasticity and adaptation. Additional risks involve innovation and technical/R&D capabilities (Güneri & Deveci, 2023; Kao, 2022; Coşkun et al., 2022) as well as production and manufacturing flexibility issues (Sahu et al., 2023).

Regarding organizational risk factors, (Sahu et al., 2023) have extensively studied this category. The primary risks include layout design issues, management ineffectiveness and capability, organizational structure challenges, insufficient speed in resource upgrades, poor adaptability to market changes, lack of internal communication agility, and difficulties in returning to a consistent and reliable operational state.

Finally, legal risk factors comprise several subcategories. (Lo, 2023) identified legal compliance, incentives, and data security as key components. Sahu et al. (2023) further included risks related to contracts and permits, while (Kao, 2022) highlighted issues with the timeliness and reliability of guarantee and warranty services.

Part 2: supplier assessment in the supply chains

In the context of supply chain management, supplier evaluation has emerged as a critical factor in maintaining sustainable and efficient operations. Although a substantial body of research has focused on supplier selection, relatively few studies address the ongoing evaluation of supplier performance after selection. Supplier evaluation extends beyond the initial selection phase and plays a pivotal role in assessing suppliers' continuous contributions to the overall success of the supply chain. This process involves the systematic monitoring and appraisal of supplier performance to ensure compliance with required standards and expectations, thereby helping to mitigate risks, reduce costs, and strengthen supplier–organization relationships.

The significance of supplier evaluation lies in its capacity to prevent potential disruptions and enhance supply chain robustness. A well-established supplier evaluation framework enables organizations to identify and resolve performance issues proactively, ensuring that suppliers remain aligned with evolving business objectives. As supply chain ecosystems become increasingly complex, particularly with the rising emphasis on sustainability, adopting rigorous evaluation procedures is essential for maintaining resilience and operational efficiency.

Key Supplier Evaluation Methods

Various methodologies have been employed in the literature to evaluate supplier performance, ranging from traditional techniques to advanced multi-criteria decision-making (MCDM) approaches. These methodologies primarily aim to assess supplier performance across multiple dimensions, including quality, cost, delivery time, and sustainability. Furthermore, sophisticated methods such as fuzzy logic, hybrid models, and multi-objective decision-making frameworks have been incorporated into supplier evaluation processes to better capture the complexity and uncertainty inherent in supplier performance.

Table 1 presents a summary of key studies in the field of supplier selection and evaluation, highlighting the methodologies applied and their corresponding outcomes.

Table 1
Main studies in suppliers evaluating and selecting

Authors	*Type*	*Methodology*
Ali & Zhang (2023)	S. Selection	MOLP Model; Multi-objective decision-making model
Bonab et al. (2023)	S. Selection	Best worst method; TRUST methods.
Wu et al. (2023)	S. Selection	The new RPN formula.
Suryadi & Rau (2023)	S. Selection	Hybrid MCDM-Optimization
Gernert et al. (2023)	S. Selection	Mathematical model.
Wissuwa et al. (2022)	S. Selection	Analysis based on a survey
Ruiz-Torres et al. (2022)	S. Selection	Decision tree model; sensitivity analysis
Kazemitash & Fazlollahtabar (2022)	S. Selection	Best-worst method
Tong et al. (2022)	S. Selection	PROMETHEE II; probabilistic language information.
Gallear et al. (2022)	S. Selection	Questionnaire
Güneri & Deveci (2023)	S. Selection	Q-rung orthopair fuzzy set based EDAS
Cagnin et al. (2016)	S. Selection	FMEA associated with AHP
Lo (2023)	S. Evaluation	(CRITIC) approach; CTOPSIS
Chen et al. (2016)	S. Selection	WGP; PGP
Baki (2021)	S. Selection	BWM; fuzzy TODIM
Sahu et al. (2023)	S. Selection	AHP; DEMATEL; SAW (simple additive weighting); Extended MOORA; ANP
Ahmadi et al. (2023)	S. Evaluation	FFUCOM; ICODAS
Coşkun et al. (2022)	S. Evaluation	ANP; PROMETHEE
Utama et al. (2022)	S. Evaluation	ANP; TOPSIS Algorithm
Kao (2022)	S. Evaluation	Fuzzy-MSGP Methods
Depczyński (2021)	S. Evaluation	AHP

This table provides an overview of how various decision-making models and techniques have been employed to address different supplier evaluation criteria, offering valuable insights into their strengths and limitations. In the supplier development phase, the case of a single manufacturer can support managerial decision-making and help supervisors allocate resources effectively across multiple suppliers (Karamoozian et al., 2024).

While traditional methods such as the Analytical Hierarchy Process (AHP) and Failure Modes and Effects Analysis (FMEA) have long been employed in supplier evaluation, recent research has increasingly emphasized the integration of sustainability factors into the evaluation process. This evolution reflects the growing significance of environmental, social, and economic dimensions in contemporary supply chain management. Incorporating sustainability criteria enables organizations to identify suppliers that align with long-term strategic and ethical objectives, thus fostering more resilient and responsible supply chain networks.

Moreover, innovative approaches like the Best-Worst Method (BWM), Fuzzy TOPSIS, and hybrid multi-criteria decision-making (MCDM) models have gained prominence for their capacity to address the complexity and uncertainty inherent in supplier evaluation. These advanced methodologies offer greater flexibility and precision, allowing decision-makers to assess suppliers across a diverse set of quantitative and qualitative criteria.

In conclusion, supplier evaluation is a critical and evolving process that demands ongoing refinement. Despite the extensive body of literature, there is still a need for more comprehensive models that effectively integrate both operational performance and sustainability considerations. The evaluation methods adopted must be adaptable to the dynamic and multidimensional nature of supply chains, providing robust support for strategic decision-making.

Part 3: Best-worst method

According to (Rodrigues et al., 2021), the BWM method, introduced by (Rezaei, 2015) is utilized to derive the weights for the criteria in a multicriteria decision problem. This is a multicriteria approach that employs linear programming techniques and is regarded as subjective because it incorporates the decision maker's preferences, which are expressed through pairwise comparisons between criteria.

The BWM was introduced as an alternative to the Analytic Hierarchy Process (AHP) and distinguishes itself by requiring a smaller number of pairwise comparisons since it only necessitates reference comparisons from the decision maker (DM). The literature showcases various applications of BWM in areas including:

- Gupta et al. (2022) used the best worst method for green operations management for sustainable development.
- In their study, Parhizgarsharif et al. (2019) employed a hybrid method that combined BWM-VIKOR and GRA techniques to rank facility locations within the construction site layout for the Mehr project in Tehran.
- Kazemitash & Fazlollahtabar (2022) applied the best worst method for the banking service.
- Abouhashem Abadi et al., (2018) applied the best worst method in evaluation of medical tourism development strategy
- Askarifar et al., (2018) applied the best worst method for the development of a framework in Iran's seashores.

The steps required to use the method are presented below (Rezaei, 2015):

Within this section, we will elucidate the procedures of BWM for deriving criterion weights.

Step 1: Establish a set of decision criteria. During this stage, we evaluate the criteria $\{C_1, C_2 \ldots, C_n$ to be employed in deciding.

Step 2. Identify the optimal (e.g., most favourable, most significant) and the least optimal (e.g., least favourable, least significant) criteria. During this phase, the decision-maker identifies the best and worst criteria in a general sense, without making direct comparisons.

Step 3. Evaluate the preference of the top criterion over all other criteria using a numerical value ranging from 1 to 9. The resulting Best-to-Other's vector will be:

$$A_B = (a_{B1}, a_{B2} \ldots, a_{Bn}) \tag{1}$$

where a_{Bj} indicates the preference of the best criterion B over criterion j. It is clear that $a_{BB} = 1$.

Step 4. Assess the preference of all criteria over the least desirable criterion using a numerical value between 1 and 9. This will yield the Others-to-Worst vector:

$$A_w = (a_{1W}, a_{2W} \ldots, a_{nW})^T \tag{2}$$

Here, a_{jW} represents the preference of criterion j over the worst criterion W. It's evident that a_{ww}. In our example, this vector illustrates the preference of all criteria over the "style" criterion (c5).

Step 5. Find the optimal weights $(w_1^*, w_2^* \ldots, w_n^*)$

The optimal weight for the criteria is the weight at which, for each pair of $\frac{W_B}{W_j}$ and $\frac{W_j}{W_w}$, we have

$$\frac{W_B}{W_j} = a_{Bj}, \quad \frac{W_j}{W_w} = a_{jw} \tag{3}$$

To fulfill these conditions for all j, we need to identify a solution where the maximum absolute differences $\left|\frac{W_B}{W_j} - a_{Bj}\right|$ and $\left|\frac{W_j}{W_w} - a_{jW}\right|$ for all j is minimized.

Considering the constraints of non-negativity and the summation condition for the weights, we arrive at the following problem:

$$\text{Min } \max_j \left\{ \left|\frac{W_B}{W_j} - a_{Bj}\right|, \left|\frac{W_j}{W_w} - a_{jW}\right| \right\} \tag{4}$$

$$\text{s.t.}$$

$$\sum_j w_j = 1$$

$$w_j > 0, \text{ for all } j$$

It can be transferred to the following problem: $\min \xi$ s.t.

$$\left|\frac{W_B}{W_j} - a_{Bj}\right| < \xi, \text{ for all } j, \tag{5}$$

$$\left|\frac{W_j}{W_w} - a_{jW}\right| < \xi, \text{ for all } j, \tag{6}$$

$$\sum_j w_j = 1$$

$$w_j \quad > \quad 0, \text{ for all } j.$$

Part 4: Fuzzy TOPSIS method

According to (Kia et al., 2014), the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) is regarded as a classical method in multiple criteria decision-making (MCDM), initially developed by Hwang and Yoon in 1981.

The chosen alternative should maintain the shortest distance from the positive ideal solution while simultaneously maximizing its distance from the negative ideal solution. The application of the Fuzzy TOPSIS technique in Iran began in a limited form in the 1990s, with instances of its usage primarily emerging in recent years.

According to (Kia et al., 2014), decision making process steps by fuzzy TOPSIS technique are as follows:

Step 1: Calculating weights vector W_j

Step 2: By normalizing the matrix derived from experts' opinions concerning the alternatives, a new matrix is created as follows:

$$\check{R} = [\check{r}_{ij}] \quad [\check{r}_{ij}]_{m*n} \tag{7}$$

$B[1\ldots,n]$ refers to the interest indices (2) and $C[1\ldots,n]$ refers to the cost indices (3)

$$\check{r}_{ij} = \left(\frac{a_{ij}}{d_j^+}, \frac{b_{ij}}{d_j^+}, \frac{c_{ij}}{d_j^+}\right), \quad j \in B, \tag{8}$$
$$d_j^+ = \max_i d_{ij} \quad \text{if } j \in B$$

$$\check{r}_{ij} = \left(\frac{a_j^-}{d_{ij}}, \frac{a_j^-}{c_{ij}}, \frac{a_j^-}{b_{ij}}\right), \quad j \in C, \tag{9}$$
$$a_j^- = \min_i a_{ij} \quad \text{if } j \in C$$

Step 3: So normalized weighted matrix is calculated as Eq. (4):

$$\check{V} = [\check{v}_{ij}]_{m*n}, \quad i = 1,2,\ldots,m, j = 1,2,\ldots,N \tag{10}$$
$$\check{v}_{ij} = \check{r}_{ij} \otimes \check{w}_j$$

Step 4: Determining the fuzzy positive ideal solution $(FPIS)^{V_j^+}$ *and fuzzy negative ideal solution* $(FNIS)^{V_j^-}$.

$$\check{V}_j^+ = \begin{cases} \max \check{v}_{ij}; & j \in \text{ to } B \\ \min \check{v}_{ij}; & j \in \text{ to } C \\ i = 1,\ldots,m \end{cases} \tag{11}$$
$$FPIS = \left\{\check{V}_j^+ \quad | j = 1,\ldots,N\right\}$$

$$\check{V}_j^- = \begin{cases} \min \check{v}_{ij}; & j \in \text{ to } B \\ \max \check{v}_{ij}; & j \in \text{ to } C \\ i = 1,\ldots,m \end{cases} \tag{12}$$
$$FNIS = \left\{\check{V}_j^- \quad | j = 1,\ldots,N\right\}$$

Step 5: Calculating the distances using Fuzzy Euclidian distance:

$$D(\check{a}\check{b}) = \sqrt{\frac{1}{3}\left[(a_1-b_1)^2 + (a_2-b_2)^2 + (a_3-b_3)^2\right]} \tag{13}$$

The distance of each alternative from positive and negative ideal is calculated as follows,

$$S_i^+ = \sum_{j=1}^{n} D(\check{v}_{ij}, V_j^+), \quad i = 1,2,\ldots,m \tag{14}$$

$$S_i^- = \sum_{j=1}^{n} D(\check{v}_{ij}, V_j^-), \quad i = 1,2,\ldots,m \tag{15}$$

Step 6: Calculate the relative closeness to the ideal solution and ranking given:

$$Cc_i = \frac{S_i^-}{S_i^+ + S_i^-}, \quad i = 1,2,\ldots,m \tag{16}$$

Part 5: Strategies to mitigate inbound supply chain risks

Over the years, both academics and industry practitioners have proposed a wide array of strategies to mitigate inbound supply chain risks. These strategies are vital for enhancing the resilience and responsiveness of supply chains, especially in an increasingly dynamic and unpredictable global environment. Based on an extensive review of the literature, a set of key mitigation practices has been identified.

A significant number of these strategies focus on reinforcing the foundational elements of the supply chain. One of the most commonly cited approaches is the use of buffer strategies. This includes maintaining higher levels of safety stock and strategic inventory buffers to absorb potential supply disruptions and demand fluctuations (Tang & Tomlin, 2008). In some cases, firms require their suppliers to hold inventory on their behalf, thereby further insulating themselves from supply volatility and ensuring continuity of operations even during upstream disturbances.

Another critical set of strategies identified in the literature pertains to the enhancement of information sharing, the establishment of trust, and the cultivation of collaborative relationships between supply chain partners. These relational practices play a key role in improving responsiveness and reducing uncertainty, particularly in periods of disruption or crisis. Numerous studies emphasize that trust and transparent communication foster proactive risk management and enable firms to respond more effectively to unexpected challenges (Manhart et al., 2020; Dehdar et al., 2018).

In addition to relational strategies, the adoption of multi-sourcing approaches has been widely recognized as an effective risk mitigation measure. By engaging with multiple suppliers, organizations reduce their dependency on any single source, thereby enhancing the resilience of their supply base. This strategy typically involves sourcing materials from different geographic regions or industry sectors, thus ensuring continuity of supply even when one provider faces disruption (Kırılmaz & Erol, 2017; Sodhi & Tang, 2012; Hariharan, s.d.).

In the realm of supplier selection, several studies advocate the integration of risk assessment criteria directly into the selection process. This approach enables firms to evaluate not only the traditional dimensions such as cost, quality, and delivery performance, but also the suppliers' resilience and capacity to manage potential disruptions. By proactively identifying high-risk suppliers at the outset, companies can establish a more robust and disruption-resilient supply base.

Moreover, the adoption of flexible contractual arrangements has emerged as a critical strategy for enhancing adaptability. Contracts that incorporate clauses allowing for adjustments in delivery schedules, volumes, or pricing structures provide organizations with the agility needed to respond to unanticipated events without severely impacting operations (Sodhi & Tang, 2012; Wang et al., 2017).

Another vital aspect concerns logistics and transportation flexibility. The ability to switch transportation modes, reroute shipments, or engage alternative logistics providers is essential for maintaining continuity in the face of disruptions. Flexible logistics contracts, designed to accommodate such changes, offer a practical risk mitigation mechanism in the event of infrastructure failures or volatile demand patterns (Sodhi & Tang, 2012; Dehdar et al., 2018; Rajesh, 2020).

Finally, the establishment of contractual obligations and well-defined risk-sharing agreements is strongly advocated in the literature as a proactive strategy for mitigating inbound supply chain risks. By embedding explicit risk-sharing clauses into contractual frameworks, organizations and their suppliers can foster a collaborative approach to managing disruptions. Such agreements typically stipulate the distribution of responsibilities and potential compensations in the event of unforeseen incidents, thereby reducing ambiguity and enhancing mutual support during crises. This collaborative risk-sharing mechanism strengthens trust, aligns incentives, and ultimately contributes to a more resilient supply chain (Kırılmaz & Erol, 2017; Dehdar et al., 2018).

Materials & Methods

This study proposes an integrated approach that combines both qualitative and quantitative elements to assess supplier-related risks in the upstream segment of the supply chain. In recent years, several researchers have advocated for the use of hybrid multi-criteria decision-making (MCDM) methodologies to enhance the robustness of risk evaluation frameworks. For instance, (Karamoozian et al., 2023) employed a DEMATEL-ANP hybrid model, while in an earlier

Table 2
Strategies for inbound supply chain risk mitigation

Strategies treated	Author
Apply the buffer strategies: Increase security stock level	(Tang & Tomlin, 2008)
Imposing suppliers to keep inventories for us	(Sharma & Bhat, 2016)
Increase information sharing, trust, and collaborative relationships	(Manhart et al., 2020; Dehdar et al., 2018)
Find alternative supply sources and apply the multi-sourcing strategy	(Kırılmaz & Erol, 2017; Sodhi & Tang, 2012; Araujo et al., 2016; Dehdar et al., 2018; Hariharan, s.d.).
Supplier selection improvement	(Yang et al., 2009)
Flexible Supply contract	(Sodhi & Tang, 2012; Wang et al., 2017)
Imposing Logistics and transportation flexibility	(Sodhi & Tang, 2012; Dehdar et al., 2018; Rajesh, 2020; Majumdar et al., 2021)
Imposing contractual obligations on suppliers and signing risk-sharing contract	(Kırılmaz & Erol, 2017; Dehdar et al., 2018)
Defined meeting with suppliers to share KPI	(Sharma & Bhat, 2016)

study, the same author (Karamoozian & Wu, 2024) applied a DEMATEL-TOPSIS approach to evaluate supply chain risks in the construction sector during the COVID-19 pandemic.

The first step in effective risk management is the systematic identification of potential risks, which can influence the achievement of project objectives. In this regard, the Project Management Body of Knowledge (PMBOK) emphasizes the importance of a structured risk classification framework to ensure the quality and effectiveness of the risk identification process (Karamoozian et al., 2019).

In line with this, the present research begins by identifying the major categories of risks affecting supply chains and their respective contributing factors. Considering the growing regulatory and societal pressures related to sustainability, environmental and social risks have been explicitly incorporated into the proposed framework. The resulting risk classification includes ten key categories: economic, quality, logistical, environmental, social and safety, collaboration, technical and innovation, organizational, legal, and institutional risks. These categories, along with their associated risk factors, are summarized in Table 3.

The subsequent phase of the research focused on assigning weights to each of the identified risk factors. To achieve this, a structured multi-step weighting approach was employed, leveraging the Best-Worst Method (BWM). Initially, for each risk category individually, a BWM-based pairwise comparison was conducted among the sub-criteria (i.e., risk factors) within that category. This intra-category analysis al-

Table 3
Risk categories and adequate risk factors

Risk category	Risk factor
Economical	Green finance (Not using green finance possibilities by firms) (RE1); High supplier bankruptcy risk and bad financial stability (RE2); Cost evaluation, structure, and risk (RE3); Cash flow risk (RE4); Bad local economic environment (RE5); The lack of financial resources to support innovation. (RE6); Insufficient improvement in delivering sustainability value to customers. (RE7); Insufficient funding for research and development (R&D). (RE8).
Quality	Quality risk (bad quality of products) (RQ1); Issue with Quality management systems (RQ2); Bad grievances handling and dealing with complaints (RQ3).
Logistical	High delivery risk and non-adequate conditions of delivery (RL1); Transportation failures and risk (RL2); Capacity risk (RL3); Over-production or over shipment management (RL4); Response service rate to customers (RL5); Issue with demand visibility or web integration (RL6); Manageability to demand and supply change (RL7); Maintainability to order processing and supplier sourcing capability (RL8); Changeability to warehouse location (RL9).
Environmental	Not using green products design (REV1); Bad pollution control and gas emission (REV2); Reuse and recycling risk (REV3); Environmental risk and not respecting environmental compliance (REV4); Non adequate waste management practices (REV5); Low renewable energy use (REV6); Issue with environmental management systems (REV7).
Social and safety	Safety risk (RS1); Social risk (issue in social management systems) (RS2); Competency risk, employees' capability and absence of training facilities and training supports (RS3); Human & labor rights risk (RS4); Non respect of corporate social governance & compliance (RS5); Bad conflict/problem-solving capability (RS6).
Cooperation and collaboration	Bad bargaining power (RCC1); Lack of external communication agility (RCC2); Lack of external integration to customer services (RCC3); Attitude/trust and transparency to share information in real time (RCC4); Bad relationship closeness (RCC5); Assessment of the previous cooperation (RCC6).
Technical and innovation	Effectiveness of manufacturing processes (RTI1); Information flow means (RTI2); cultural product improvement (RTI3); Technological plasticity and adaptation (RTI4); Innovation & technical/R&D solutions capability risk (RTI5); Degree of online solution (RTI6); Production and manufacturing flexibility (RTI7).
Organizational	Layout design issue (ROR1); Management ineffectiveness and capability (ROR2); Organizational structure (ROR3); Bad quickness to resource upgradation (ROR4); Bad adaptability to market Changes (ROR5); Internal communication agility (ROR6); Difficulty to return to the initial state (consistency) and reliability (ROR7).
Legal and institutional	Contracts and permits (RLI1); Legal compliance (RLI2); Incentives (RLI3); data Security (RLI4); Bad Momentum to guarantee/ warranty service (RLI5).

lowed for the assessment of the relative importance of each risk factor in its respective category.

In parallel, a second BWM analysis was carried out to compare the major risk categories themselves (e.g., economic, quality, logistical, environmental, etc.), thereby determining their overall significance in the supply chain risk landscape. The pairwise comparisons – both within and across categories – were based on the preference scale introduced by (Rezaei, 2015), as presented in Table 4.

Table 4
Scale proposed by (Rezaei, 2015) for the criteria pairwise comparison

Value	*Linguistic value*
1	Equal importance
2	Somewhat between equal and moderate
3	Moderately more important than
4	Somewhat between moderate and strong
5	Strongly more important than
6	Somewhat between strong and very strong
7	Very strongly important than
8	Somewhat between very strong and absolute
9	Absolutely more important than

Once the individual weights were computed, the final "global" weight for each risk factor was calculated. This was done by multiplying the local weight of the factor within its category by the overall weight assigned to the corresponding risk category. This approach ensured a hierarchical and coherent weighting system, capturing both the intra- and inter-category importance of the risk dimensions.

The final global weight of each risk factor was obtained by multiplying its local weight – derived from the intra-category BWM analysis – by the weight of its corresponding risk category – determined through the inter-category BWM analysis. The pairwise comparisons in both stages were based on the scale proposed by (Rezaei, 2015), as shown in Table 4.

The identification of suppliers to be evaluated constitutes a crucial step for the continuation of this research. The study was conducted on a segment of a multinational automotive company operating in Morocco, which supplies assembled components to final OEMs. Due to confidentiality constraints, the name of the company and its suppliers will not be disclosed.

To proceed, a fuzzy decision matrix was constructed, along with a matrix reflecting the relative importance of the evaluation criteria, using linguistic (verbal) scales. The alternatives to be ranked correspond to the suppliers, while the main evaluation criteria are the identified risk factors. The next phase involved normalizing the fuzzy decision matrix and calculating the weighted normalized fuzzy decision matrix. This allowed for the determination of the fuzzy positive ideal solution (FPIS) and the fuzzy negative ideal solution (FNIS), followed by the computation of the closeness coefficient for each supplier.

In the final stage, suppliers were ranked based on their closeness coefficients, and tailored strategies were proposed accordingly. The methodological steps adopted in this process are illustrated in Figure 2.

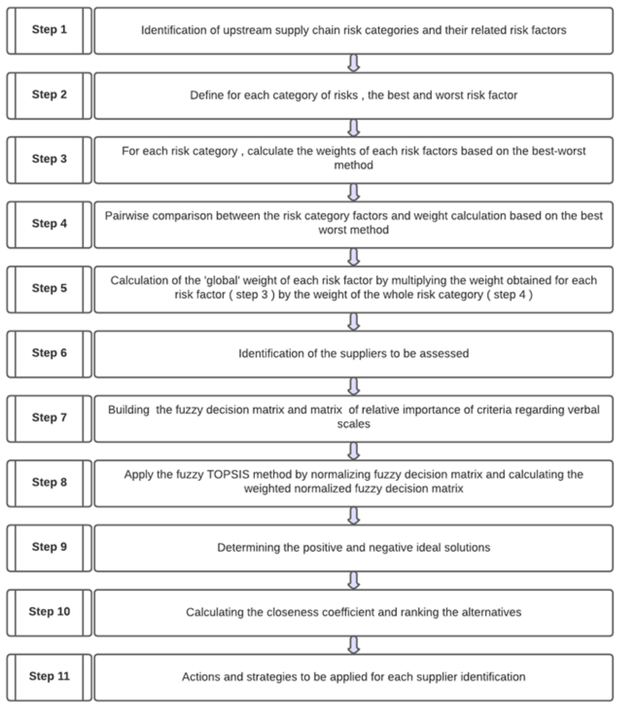

Fig. 2. Steps of the methodology proposed for suppliers' evaluation

Results and discussion

To implement the proposed methodology, we conducted a case study within a multinational company operating in the automotive sector, specifically involved in assembling components for a French original equipment manufacturer (OEM), Renault. With the collaboration of the company's supply chain manager, we selected a specific production segment: the assembly of metallic parts. During our interviews, six key suppliers involved in this process were identified – one located in Morocco, four in Europe, and one in Asia.

As a first step, the list of risk factors presented in Table 4 was reviewed and validated by the decision-maker to ensure contextual relevance. Subsequently, we proceeded with the second stage of the methodology by asking the logistics manager to identify the most critical (best) and least critical (worst) criteria for evaluating supplier-related risks. Table 5 presents a summary of the data collected for each risk category.

Following the same approach, the best and worst criteria for each risk category were identified. The decision-maker recognized the 'logistics' risk category as the most critical, whereas the 'social and safety' risk category was considered the least significant. Using the Best-Worst Method (BWM) and the collected data, the weights of risk factors within each category were calculated separately, by applying equations (1) through (6). Furthermore, the relative weights of each risk category were determined through pairwise comparisons.

By multiplying these values, we derived global weight for each risk factor, as shown in Table 6.

The fuzzy TOPSIS method was applied to assess each supplier based on the identified risk factors. To this end, the decision-maker was asked to assign values and ratings for each risk factor per supplier. Due to the inherent uncertainties associated with linguistic assessments, the fuzzy TOPSIS approach was selected instead of a traditional method. The input data provided by the decision-maker are summarized in Table 7.

To ensure accurate numerical representation, linguistic values were translated into fuzzy numbers based on the scale provided in Table 8.

Each risk factor was classified as either "beneficial" or "non-beneficial". As all risk factors in this study negatively influence supply chain performance, they were categorized as "non-beneficial", meaning that higher values indicate a more detrimental impact.

In accordance with the fuzzy TOPSIS methodology, and by applying equations (7) through (16), the normalized weighted matrix was computed. This process enabled the identification of the fuzzy positive ideal solution and the fuzzy negative ideal solution. Subsequently, distances were calculated using the Fuzzy Euclidean distance, allowing for the determination of the relative closeness to the ideal solution and the final ranking of suppliers, as presented in Table 9.

The ranking results indicate that Supplier 2 is the lowest-performing, followed by the Moroccan-based Supplier 3. Supplier 1 ranks third, while Suppliers 4, 5, and 6 demonstrate the highest performance and present the least risk.

Based on the obtained rankings, a set of actions was developed. A focus group involving relevant stakeholders was convened to discuss the outcomes. All risk mitigation strategies presented in Table 2 (literature review) were validated by the focus group. It was recommended that regular meetings – on a monthly basis or at another suitable frequency – be scheduled to review supplier performance and determine appropriate actions for each supplier.

Regarding Supplier 1, which was identified as the best-performing supplier in the study, the focus group concluded that no immediate mitigation strategies were necessary due to its strong performance.

Table 5
Risk category best and worst criteria

Risk category	*Best criteria*	*Worst criteria*
Economical	High Supplier bankruptcy risk and bad financial stability	Lack of Finance in R&D
Quality	Quality risk (bad quality of products)	Issue with Quality management systems
Logistical	High Delivery risk and non-adequate conditions of delivery	Changeability to warehouse Location
Environmental	Environmental risk and not respecting environmental compliance	Reuse and recycling risk
Social and safety	Safety risk	Non respect of corporate social governance & compliance
Cooperation and collaboration	Attitude/trust and transparency to share information in real time	Lack of External communication Agility
Technical and innovation	Effectiveness of manufacturing processes	Degree of online solution
Organizational	Management ineffectiveness and capability	Layout design issue
Legal and institutional	Contracts and permits	Incentives

Table 6
Global weight for each risk factor

Risk family	*Risk Family weight (W1)*	*Risk Factor code*	*Risk factors Weights (w2)*	*Global risk weight*
Economical	0.100	RE1	0.034	0.003
		RE2	0.158	0.016
		RE3	0.073	0.007
		RE4	0.220	0.022
		RE5	0.110	0.011
		RE6	0.198	0.020
		RE7	0.110	0.011
		RE8	0.096	0.010
Quality	0.075	RQ1	0.500	0.038
		RQ2	0.200	0.015
		RQ3	0.300	0.023
Logistical	0.254	RL1	0.176	0.045
		RL2	0.106	0.027
		RL3	0.176	0.045
		RL4	0.071	0.018
		RL5	0.106	0.027
		RL6	0.106	0.027
		RL7	0.106	0.027
		RL8	0.106	0.027
		RL9	0.047	0.012
Environmental	0.075	REV1	0.080	0.006
		REV2	0.224	0.017
		REV3	0.072	0.005
		REV4	0.288	0.022
		REV5	0.096	0.007
		REV6	0.144	0.011
		REV7	0.096	0.007
Social and safety	0.041	RS1	0.212	0.009
		RS2	0.273	0.011
		RS3	0.136	0.006
		RS4	0.212	0.009
		RS5	0.076	0.003
		RS6	0.091	0.004
Cooperation and collaboration	0.151	RCC1	0.088	0.013
		RCC2	0.055	0.008
		RCC3	0.132	0.020
		RCC4	0.242	0.037
		RCC5	0.242	0.037
		RCC6	0.242	0.037
Technical and innovation	0.100	RTI1	0.250	0.025
		RTI2	0.100	0.010
		RTI3	0.100	0.010
		RTI4	0.100	0.010
		RTI5	0.100	0.010
		RTI6	0.050	0.005
		RTI7	0.300	0.030

Table continued on the next page

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Risk family	*Risk Family weight (W1)*	*Risk Factor code*	*Risk factors Weights (w2)*	*Global risk weight*
Organizational	0.100	ROR1	0.038	0.004
		ROR2	0.245	0.025
		ROR3	0.149	0.015
		ROR4	0.149	0.015
		ROR5	0.099	0.010
		ROR6	0.075	0.008
		ROR7	0.245	0.025
Legal and institutional	0.100	RLI1	0.250	0.025
		RLI2	0.250	0.025
		RLI3	0.100	0.010
		RLI4	0.250	0.025
		RLI5	0.150	0.015

Table 7
Data received from the DM

Sup.	*Economical*								*Quality*			*Logistical*								
	RE1	RE2	RE3	RE4	RE5	RE6	RE7	RE8	RQ1	RQ2	RQ3	RL1	RL2	RL3	RL4	RL5	RL6	RL7	RL8	RL9
1	A	L	A	VL	A	VL	A	L	A	H	A	H	VH	H	L	A	VL	H	H	L
2	H	VL	VL	L	H	L	A	L	A	H	VH	VH	H	VH	VL	H	H	H	VH	L
3	H	A	H	H	H	A	L	L	H	H	H	A	L	VL	L	H	L	L	L	L
4	VH	H	H	H	L	A	A	H	L	L	VL	VL	VL	VL	L	L	VH	VL	L	L
5	H	A	H	H	A	L	H	H	VL	L	L	A	VL	L	VL	A	VH	L	H	VL
4	VH	H	H	H	A	A	A	VH	A	L	VL	L	L	L	L	L	H	L	VL	L

Sup	Environmental							Social and safety						Cooperation and collaboration					
	REV1	REV2	REV3	REV4	REV5	REV6	REV7	RS1	RS2	RS3	RS4	RS5	RS6	RCC1	RCC2	RCC3	RCC4	RCC5	RCC6
1	A	L	L	VL	VL	A	L	VL	L	H	H	A	L	H	L	VL	H	L	L
2	L	A	L	L	L	H	L	L	L	A	A	A	L	H	H	L	H	A	H
3	H	A	H	H	H	H	L	L	L	A	L	L	L	A	L	L	L	L	L
4	H	A	A	L	L	H	A	L	L	L	L	L	L	VL	L	H	L	L	L
5	VH	A	A	L	L	H	A	L	L	L	L	L	L	A	VL	H	VL	L	L
6	VH	VH	VH	L	L	H	A	L	L	L	L	L	L	VL	L	H	L	L	L

Sup	Technical and innovation							Organizational							Legal and institutional				
	RTI1	RTI2	RTI3	RTI4	RTI5	RTI6	RTI7	ROR1	ROR2	ROR3	ROR4	ROR5	ROR6	ROR7	RLI1	RLI2	RLI3	RLI4	RLI5
1	L	L	VL	VL	VL	VL	H	L	A	VL	H	VL	VL	L	L	VL	VL	VL	VL
2	A	L	L	VL	VL	L	H	VL	L	L	L	L	A	H	H	L	L	L	L
3	L	L	L	L	L	A	A	L	L	L	L	L	L	L	A	VL	VL	L	L
4	L	VH	VH	H	H	H	L	L	L	L	L	L	L	A	L	L	L	A	L
5	L	VH	VH	H	VH	VH	L	L	VL	VL	L	L	L	L	L	L	L	L	L
6	L	VH	VH	H	VH	VH	L	L	L	L	L	L	L	A	VL	VL	L	L	L

Table 8
Terms and adequate fuzzy number

Term	*Fuzzy Number*
Very low	1,1,3
Low	1,3,5
Average	3,5,7
High	5,7,9
Very high	7,9,9

Table 9
Final ranking obtained

	Di+	Di-	Cci	Final Ranking
Supp. 1	0.299157218	0.281467258	0.4847664	4
Supp. 2	0.455235668	0.143919299	0.2402038	6
Supp. 3	0.347556916	0.271168743	0.4382698	5
Supp. 4	0.282319268	0.323879702	0.5342795	1
Supp. 5	0.298603739	0.309169619	0.5086923	2
Supp. 6	0.318234499	0.302636231	0.4874384	3

For Suppliers 5 and 6, the focus group recommended the implementation of two specific strategies: (1) scheduling regular meetings with suppliers to share Key Performance Indicators (KPIs), and (2) requiring suppliers to maintain inventory on behalf of the company.

Supplier 1, ranked fourth, was reported by management to be facing difficulties in securing components from its own suppliers, which hinders its ability to meet demand. As a result, several mitigation strategies were selected. First, the application of buffer strategies was recommended by establishing an internal safety stock equivalent to 15 days of demand in order to reduce the risk of shortages. However, the strategy of requiring the supplier to maintain inventory was deemed inapplicable in this case, as the supplier operates on a make-to-order basis and directly ships received components to the production site.

The strategy to increase information sharing, build trust, and enhance collaborative relationships was also endorsed. To achieve this, the supplier will be asked to provide direct access to its inventory management system, thereby enabling real-time visibility into component availability.

Other strategies such as identifying alternative supply sources or improving supplier selection processes were considered inapplicable by the managers, since this supplier holds a monopoly in its technological domain and is currently the only available producer of these specific components.

The strategy of imposing logistics and transportation flexibility was deemed necessary for this supplier by requiring the use of express delivery methods (e.g., air transport) to mitigate delays caused by upstream supply issues. Additionally, regular KPI review meetings were scheduled, with weekly sessions planned to monitor supply performance and progress.

The two most critical suppliers identified were Supplier 3 and Supplier 2. In the case of Supplier 3, who operates within the same country as the production site, the strategy of increasing internal safety stock was considered unnecessary due to geographical proximity. Instead, it was decided to impose inventory requirements on the supplier by extending the stock coverage period held at the supplier's premises.

The strategy to enhance information sharing and collaboration was assessed as non-essential for this supplier. Conversely, the strategy of identifying alternative supply sources and applying a multi-sourcing approach was recommended. Potential substitutes located in other countries could serve as contingency options in the event of a disruption.

Furthermore, the specialists decided to renegotiate the contract terms with this supplier to include a flexible supply clause, allowing for quantity variations of approximately 30% in order to better absorb demand fluctuations and reduce risk exposure.

Given the supplier's close geographical location, decision-makers concluded that no special transportation measures were necessary, as logistical disruptions had been infrequent. However, during contract renegotiations, the inclusion of explicit contractual obligations and risk-sharing clauses was approved. These provisions aim to address potential non-deliveries and ensure shared responsibility in case of disruptions.

Supplier 2 was identified as the most critical among all evaluated suppliers. Its location on a different continent and the high frequency of production stoppages present a significant threat to the continuity of the supply chain. Consequently, it was decided to implement all applicable mitigation strategies from the predefined framework. This comprehensive approach seeks to reduce dependency and enhance supply chain resilience in relation to this high-risk supplier.

Conclusion

Supplier evaluation, incorporating sustainability criteria, plays a crucial role in enhancing a company's sustainability performance and advancing its development goals more effectively. The primary objective of this study was to assess the supply chain performance of suppliers for a multinational automotive company by presenting a critical review of supply chain risk factors related to sustainability.

This research proposes an innovative model that combines the Best-Worst Method (BWM) and Fuzzy TOPSIS, offering decision-makers a simplified yet robust approach and guidelines for supplier evaluation, while considering the constraints imposed by available business resources. Given the inherent ambiguity and uncertainty in supplier evaluation, fuzzy set theory has proven valuable for capturing decision-makers' preferences expressed through linguistic terms to assess each supplier's criteria.

The results indicate that Supplier 2 is the main source of supply chain risks for the company, followed by Supplier 3, Supplier 1, and the remaining suppliers. These insights enabled the logistics manager to implement corrective actions, particularly targeting the most critical suppliers, with the goal of mitigating risks and improving overall business performance.

However, the study has certain limitations, notably its focus on a single case within the automotive industry. Consequently, the findings may not be generalizable to all supply chains in industrial enterprises or applicable across different sectors or geographic regions. Future research could explore alternative multi-criteria decision-making (MCDM) methods such as ANP, AHP, MICMAC, Fuzzy VIKOR, EDAS, SEM, or PROMETHEE to further validate and compare supplier evaluation criteria. Additionally, subsequent studies could extend this framework to other industrial sectors or emerging economies, building on the current findings to evaluate suppliers based on sustainability considerations.

In summary, this research provides a solid foundation for advancing sustainable supply chain management and supplier evaluation, particularly in diverse geographical and industrial contexts, thereby contributing to the broader field of supply chain risk management and sustainability.

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