University of Tehran Press

Industrial Management Journal

Online ISSN: 3115 - 7386

Homepage: https://imj.ut.ac.ir

Evaluating Blockchain Technology Implementation Risks in the Automotive Industry: A Fuzzy Decision-Making Approach

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Article Info

Article type:
Research Article

Article history:
Received January 03, 2026
Received in revised form February 17, 2026
Accepted March 09, 2026
Available online April 01, 2026

Keywords:
Blockchain, fuzzy multi-criteria decision-making, automotive industry, small and medium-sized enterprises, supply chain.

ABSTRACT

Objective: This study aims to identify and prioritize the potential risks associated with adopting blockchain technology in the supply chain of Small and Medium-sized Enterprises (SMEs) operating in the automotive industry.

Methodology: A fuzzy Multi-Criteria Decision-Making (MCDM) approach is employed. The Stepwise Weight Assessment Ratio Analysis (SWARA) method is used to determine the relative importance of identified blockchain implementation risks while accounting for ambiguity and subjectivity in expert judgments. The proposed framework is validated through a case study involving SMEs in the automotive sector, where expert evaluations are collected and modeled using fuzzy numbers to improve the robustness and accuracy of the results.

Results: The findings indicated that security, technical, and organizational risks were the most important ones. Additionally, the sub-risks of privacy/confidentiality of information, lack of necessary policies and regulations, and cyber-attacks with values of 0.1224, 0.0933, and 0.0927 were recognized as the most critical, respectively. These results highlight the areas that require immediate managerial and regulatory attention to ensure successful blockchain implementation.

Conclusion: This study demonstrates that integrating fuzzy sets with SWARA method provides a systematic and reliable approach for assessing blockchain adoption risks under uncertainty. The proposed framework offers practical guidance for supply chain managers and policymakers seeking to mitigate implementation risks and achieve sustainable competitive advantages through blockchain technology.

Cite this article: Hosseini Dehshiri, J., & Amiri, M., (2026). Evaluating blockchain technology implementation risks in the automotive industry: A fuzzy decision-making approach, *Industrial Management Journal*, 18(2), 242-269. https://doi.org/10.22059/imj.2026.410718.1008287

Publisher: University of Tehran Press.

DOI: https://doi.org/10.22059/imj.2026.410718.1008287

Introduction

Companies are using advanced tech to be better and beat the competition. Deciding to adopt the latest technology is essential for companies and can significantly impact their operations. So, it is necessary to consider the adoption of new technology and reap its advantages (Yousefi et al., 2026). In this regard, it is necessary to analyze possible risks and manage existing risks to reduce the probability of project failure and improve the system's effectiveness (Nikolaenko & Sidorov, 2023). When technology is considered one of the main infrastructures of the organization, its importance increases. Blockchain technology can serve as the main infrastructure in organizations' systems in the near future (Iranmanesh et al., 2023).

Blockchain technology is an advanced and revolutionary protocol that has the potential to transform industries, the structure, and scope of organizations, as well as the way business dealings are carried out (Abdollahi et al., 2026). A distributed database system called blockchain verifies transactions without the need for a central authority (Salaj & Kumari, 2025). Blockchain technology uses a decentralized network of computers where each member has a copy of the entire blockchain for easy tracking and auditing of past transactions (Hosseini Dehshiri & Amiri, 2024). Because transaction records are linked to one another and any manipulation of transaction records is reported on the network, every transaction in this technology is verified using public-private key cryptography and cannot be readily removed or altered once it has been verified and stored. Data security is thus preserved within the blockchain network (Dehshiri et al., 2022). Blockchain's peer-to-peer framework can improve efficiency and transparency, reduce costs, and create an immutable audit trail for transactions, revolutionizing business processes by separating central entities (Gad et al., 2022).

As an advanced technology, blockchain has attracted the attention of stakeholders in many industrial fields, including logistics and supply chain (Sadeghi et al., 2023). Today, supply chains have very complex structures, with a high level of geographical dispersion, many tasks, and stakeholders with diverse cultures, and many organizations do not have an integrated view of the entire supply chain (Hosseini Dehshiri & Amiri, 2024). Lack of transparency in terms of security, tracking, authentication, and verification system creates many problems and dilemmas. The adoption of blockchain technology with immutability, transparency, and reliability features is appropriate and vital to address the risks and challenges (Saberi et al., 2019). Blockchain technology can effectively record every asset along the supply chain and track orders, receipts, payments, and digital assets such as warranties and licenses in a seamless and transparent manner (Agi & Jha, 2022). In the blockchain, each member in the supply chain can reliably track and evaluate products, shipments, deliveries, and progress, and communicate and exchange information with other members. Also, the need to use intermediaries and auditors among the members of the supply chain is eliminated and a broad and integrated view of the entire value chain is created (Hosseini Dehshiri et al., 2024). Therefore, a blockchain-based supply chain increases efficiency, reduces workload, costs, paperwork, and human errors, and ensures more authenticity and quality of products and data security (Hosseini Dehshiri et al., 2024).

Adopting blockchain can effectively facilitate the supply chain, but its implementation involves many risks and challenges, and for the efficient and effective use of blockchain, these risks must be carefully identified and analyzed to avoid their adverse effects (Özkan et al., 2020). Information transparency is one of the advantages of using blockchain in the supply chain. With increased transparency, transactions become more efficient and the relationship between suppliers and customers improves. On the other hand, extensive information exchange amongst supply chain parties may inadvertently damage privacy and alter market structure. Effective data management and privacy concerns should be addressed in order to prevent such negative outcomes. If not, blockchain could be abused to seize control of the market and abuse personal authority (Adam & Fazekas, 2021).

This research will comprehensively assess the potential risks of implementing blockchain technology in the automotive sector through the Multi-Criteria Decision-Making (MCDM) approach. To consider ambiguity and uncertainty in evaluations, fuzzy numbers, and the Stepwise Weight Assessment Ratio Analysis (SWARA) technique are utilized in this research for weighting identified risks. To prove the potency of the research methodology, a case study was executed on Small and Medium-sized Enterprises (SMEs) operating in the automotive sector. The SMEs are one of the most reliable suppliers of auto parts and have a high share of the national gross product, in all parts of its life cycle (from exploitation of natural resources to consumption and after consumption). Due to the rapid changes in technology and uncertainty in the activities of this industry, non-compliance with new technologies can reduce competitiveness and customer satisfaction and ultimately reduce profitability. In this regard, supply chain managers should always act to adopt and implement these technologies in an optimal way and to gain a sustainable competitive advantage. The innovations and important contributions of this research are:

- Focusing on the studied concept and the usage of blockchain and identifying the most important blockchain risks in SMEs in the automotive industry, which is currently still in the initial stages and requires the examination of various aspects of its application.

- To assess the risks of using blockchain in the parts manufacturing industry, MCDM techniques, and the SWARA procedure can be helpful. The SWARA method is particularly reliable as it confirms experts' opinions on weighting, and collaboration among experts improves accuracy.
- Considering the uncertainty in the assessment of identified risks and proposing the use of fuzzy numbers, which leads to an increase in the accuracy of the results. Blockchain technology can help reduce some of the risks of supply chain management by providing transparency, traceability, and security. Also, the fuzzy SWARA approach can help SMEs adopt successful strategies against the risks of blockchain implementation.

The structure of the article includes different sections, in the second section, the literature has been fully examined from both theoretical and experimental aspects. In the third section, the materials and method are comprehensively discussed and in the fourth section, the research findings are stated. In the fifth section, discussions and insights are presented, and finally, in the sixth section, conclusions and research, and implementation suggestions are reviewed and presented.

Literature Background

Blockchain: concepts and structure

Blockchain can be explained as chains of a series of connected blocks that uses encryption, timestamps, and connections between blocks to record data (Hashim, 2023). Blocks in the blockchain contain unique transaction hash codes that require thorough verification before being added to the network (Lim et al., 2021). Members confirm and merge transaction hashes to create new blocks in the chain as a means of agreeing (Sharma & Kumar, 2023). When data is changed in a block, it affects the hash of that block and the hashes of the following blocks. Any attempts to modify the data will be stopped, and if there is a difference in the hashes, the following blocks will no longer be valid. (Kouhizadeh et al., 2021). The overall structure of the blockchain is presented in Figure 1.

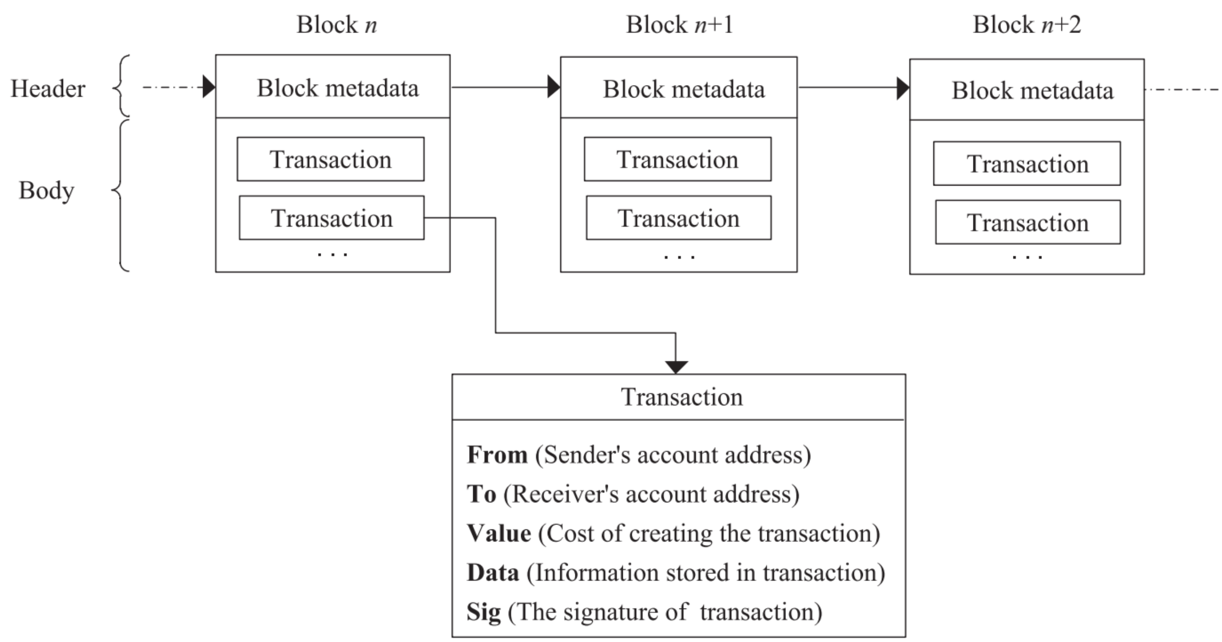

Figure 1. The overall structure of the blockchain (Zhang et al., 2023)

Nakamoto (2008) introduced Blockchain as a component of Bitcoin. This peer-to-peer electronic payment system operates through decentralized networks and manages transactions and issuance of bitcoins without the need for a central authority or bank (Hughes et al., 2019). Over time, the original ideas behind Bitcoin have expanded to include a wider range of economic and commercial uses (Hawlitschek et al., 2018). Currently, blockchain is mostly used in digital currencies and the digital economy. Blockchain technology provides numerous advantages to various industries, such as asset management, currency transactions, identity verification, and various others (Kouhizadeh et al., 2021). Although blockchain offers companies many opportunities, it can only be useful for activities that are compatible with this technology, for example, when data transparency or immutability is required. However, if the transaction rate is important, this technology will not be suitable (Özkan et al., 2020); Therefore, in addition to paying attention to the benefits of this technology, organizations should also be aware of its risks. Not considering the possible risks and challenges, the costs paid due to adverse effects outweigh the expected economic and social benefits (Drljevic et al., 2020). Several researchers have investigated the challenges and risks associated with the adoption and use of blockchain, the most important of which are mentioned below.

Risk management in blockchain technology

The use of blockchain technology has the potential to combat corruption and give power to communities. However, it is important to manage potential risks to prevent any negative effects and promote sustainable growth. A study conducted by Kim and Kang (2017) delved into this topic. Zheng et al. (2018) organized blockchain technology into categories, explained how consensus algorithms work, explored its potential applications, and identified technical risks. They also examined recent developments aimed at minimizing those risks. According to a study by Hughes et al. (2019), blockchain technology has the potential for widespread adoption in various industries. The study reviewed existing research literature and explored real-world examples. However, there are significant challenges that need to be addressed before they can be fully integrated into business operations. According to a study conducted by Saberi et al. (2019), there are four main categories of obstacles that hinder blockchain in supply chain management. These include inter-organizational barriers, intra-organizational obstacles, technical challenges, and external factors. According to a study conducted by Litke et al. (2019), blockchain technology has the potential to enhance supply chain management. However, further research and the resolution of technical obstacles are required to establish a universal blockchain system.

In their research, Dutta et al. (2020) explored blockchain in supply chain implementation. They found that it has potential uses across various industries. Research by Drljevic et al. (2020) found that effective risk management is crucial for the successful use of blockchain technology. They analyzed standards and potential risks and presented risk management models to address them. Janssen et al. (2020) studied blockchain technology adoption and created a framework showing the relationships between institutional, market, and technical factors. Özkan et al. (2020) evaluated and prioritized the risks of blockchain tech using Pythagorean fuzzy hierarchy analysis. Security risks were found to be the most important, and managers should give them more priority. Sanka et al. (2021) studied the uses and risks of blockchain through cryptography and quantitative analysis of public and enterprise blockchains.

A study by Kouhizadeh et al. (2021) found that technical barriers are the main hindrance to blockchain adoption, according to experts in academia and industry. The DEMATEL technique was used to analyze the barriers. Mohammad and Vargas (2022) qualitatively investigated the challenges of adopting blockchain in higher education, identifying 15 key challenges through 14 interviews with academic and administrative staff from the EU and Canada. However, the study did not evaluate these challenges. In a review study, Wenhua et al. (2023) examined the challenges and future trends of blockchain implementation in healthcare. The findings of this study focused on security risks as a challenge affecting the implementation of blockchain, and the evaluation and prioritization of the challenges of implementing this technology was not done in this work. Liu et al. (2023) conducted a literature review to identify the major challenges of blockchain in the maritime supply chain. While the study provided new insights, the identified challenges were not evaluated or prioritized. Khan et al. (2023) used the BWM technique to assess the main challenges of implementing blockchain in the food supply chain. However, the study did not consider uncertainty in the evaluations.

Çıkmak et al. (2024) explored how different features of blockchain shape supply chain performance within the SCOR framework. Using an integrated Interval Type-2 Fuzzy AHP and TOPSIS approach, the authors show that decentralization, security, and immutability have the strongest impact on supply chain outcomes, whereas consensus is relatively less influential. Overall, the findings suggest that blockchain adoption primarily improves reliability and asset management efficiency, providing clear and practical guidance for organizations aiming to strengthen their supply chain performance. Salaj and Kumari (2025) developed a comprehensive decision-making framework to compare and rank blockchain technologies used in supply chain management. By combining Entropy and CRITIC weighting with well-established MCDM techniques, namely WSM, TOPSIS, and VIKOR, their approach evaluates blockchain platforms across a broad set of performance criteria. The findings offer reliable and practical guidance for selecting blockchain solutions that enhance both sustainability and efficiency in supply chain networks. Abdollahi et al. (2026) proposed a fuzzy ZE-based decision framework to assess sustainable blockchain adoption strategies in the solar energy supply chain. Results from Turkey indicate that government-led collaboration and adaptive energy management solutions are the most effective options. The findings confirm the robustness of the model and underscore blockchain’s role in enhancing transparency and sustainability in renewable energy systems. Table 1 summarizes research on Risk management in blockchain technology.

Table 1. Summary of studies on Risk management in blockchain technology

Author(s)	Objective	Main focus	Method(s)	Findings and limitations
Zheng et al. (2018)	Examination of classification and applications of blockchain	Identifying technical risks	-	Highlighting the high potential of blockchain for widespread adoption
Hughes et al. (2019)	Blockchain adoption in industries	Examination of risks and challenges in business operations	-	Exploring blockchain's potential across various industries
Saberi et al. (2019)	Blockchain in supply chain	Examination of blockchain risks in supply chain	-	Identifying inter-organizational, intra-organizational, technical, and external risks

Author(s)	Objective	Main focus	Method(s)	Findings and limitations
Litke et al. (2019)	Enhancing supply chain with blockchain	Examination of blockchain risks	-	Demonstrating the high potential of blockchain in supply chain management, while addressing technical risks and challenges in this area
Janssen et al. (2020)	Blockchain adoption framework	Examination of institutional, market, and technical factors and risks	-	Analyzing the interactions between factors influencing blockchain adoption
Özkan et al. (2020)	Prioritizing risks of blockchain adoption	Identifying and assessing risks	Pythagorean fuzzy analysis	Identifying security risks as the primary concerns
Sanka et al. (2021)	Examination of blockchain uses and risks	Analysis of key challenges and risks of blockchain	-	Emphasizing the need for a comprehensive risk assessment
Kouhizadeh et al. (2021)	Analyzing the barriers of blockchain	Identifying risks of blockchain adoption	DEMATEL	Recognizing technical risks as key challenges
Mohammad and Vargas (2022)	Blockchain in higher education	Identifying 15 key challenges and risks	-	The need for a thorough evaluation of challenges and risks
Wenhua et al. (2023)	Blockchain in healthcare	Identifying risks in healthcare sector	-	Identifying security risks as the primary concerns in blockchain adoption within the healthcare sector
Liu et al. (2023)	Blockchain in maritime supply chain	Identifying key blockchain challenges and risks in maritime sector	-	The necessity of prioritizing key challenges and risks for effective implementation
Khan et al. (2023)	Blockchain in food supply chain	Identifying key risks in food sector	BWM	The importance of considering uncertainty in risk evaluation processes
Çıkmak et al. (2024)	Blockchain features and supply chain performance	Blockchain performance risks	Interval Type-2 Fuzzy AHP and TOPSIS	Highlighting decentralization, security, and immutability as key factors and associated risks in blockchain adoption
Salaj and Kumari (2025)	Blockchain technology comparison	Blockchain risks in selecting blockchain	Entropy and CRITIC with MCDM	Providing practical guidance for selecting appropriate blockchain solutions
Abdollahi et al. (2026)	Sustainable blockchain adoption	Examination of blockchain risks and strategies in the solar energy supply chain	Fuzzy ZE-based MCDM framework	Introducing government collaboration and adaptive energy management as essential solutions for successful implementation

Research gap

According to the literature, most of the studies that have been done so far in the field of risks and challenges of blockchain technology implementation, have only been examined in a review form, and only a few of the mentioned studies have assessed and prioritized the challenges in a case study. Organizations fail if they fail to take into account the relative importance of blockchain implementation risks and challenges, according to the aforementioned analysis. Another weakness of previous research was the problem tree's partial and limited view, which failed to adopt a comprehensive view of all risks. On the other hand, in many studies, the issue of uncertainty in the evaluation of experts in decision-making approaches has not been paid attention to, which has a great impact on the accuracy and validity of the findings. In addition, not using a group MCDM approach that takes into account the opinion of all the stakeholders of the issue in question was another gap in this field. Therefore, the current research tries to, by using a comprehensive and detailed review of all the raised risks in the research literature and using group MCDM techniques such as the SWARA method based on fuzzy numbers, while considering the uncertainty in the evaluations, specify the importance of the most important risks of blockchain implementation.

Materials and Methods

In this section, the set of fuzzy numbers and the mathematical relations of fuzzy numbers are first described. Then fuzzy SWARA approach is explained to determine the importance of blockchain implementation risks in SMEs in the automotive industry.

Fuzzy numbers sets

The theory of fuzzy sets, which was invented by Zadeh (1965), is one of the most useful tools to deal with ambiguity and uncertainty in human mental judgments. According to Zimmermann (2011), it is easier to use verbal expressions instead of exact and definite numbers when making decisions to express judgments and preferences.

There are different types of fuzzy numbers including trapezoidal, triangular, and Exponential numbers. Amongst, Triangular Fuzzy Number (TFN) has been used in this study as the most intelligible and popular one by academics.

$$\mu_{\widetilde{M}}(x) = \begin{cases} 0 & x \in (-\infty, l) \\ \dfrac{x-l}{m-l} & x \in [l,m] \\ \dfrac{u-x}{u-m} & x \in [m,u] \\ 0 & x \in (u,\infty) \end{cases} \quad (1)$$

Figure (2) represents triangular fuzzy number with membership function $\boldsymbol{\mu_{\widetilde{M}}(x)}: \boldsymbol{R} \rightarrow [\boldsymbol{0}, \boldsymbol{1}]$.

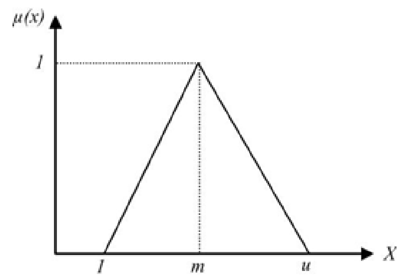

Figure 2. Triangular fuzzy number (Mikaeil et al., 2013)

Some computational operators on triangular fuzzy numbers $\boldsymbol{\widetilde{M}_1} = (\boldsymbol{l_1}, \boldsymbol{m_1}, \boldsymbol{u_1})$ and $\boldsymbol{\widetilde{M}_2} = (\boldsymbol{l_2}, \boldsymbol{m_2}, \boldsymbol{u_2})$ are described as bellow (Eq. (2) to Eq. (9)) (Nõlvak et al., 2013):

$$\widetilde{M}_1 \oplus \widetilde{M}_2 = (l_1 + l_2, m_1 + m_2, u_1 + u_2) \quad (2)$$

$$\widetilde{M}_1 \ominus \widetilde{M}_2 = (l_1 - u_2, m_1 - m_2, u_1 - l_2) \quad (3)$$

$$\widetilde{M}_1 \otimes \widetilde{M}_2 = (l_1 l_2, m_1 m_2, u_1 u_2) \quad (4)$$

$$\lambda \otimes \widetilde{M}_1 = (\lambda l_1, \lambda m_1, \lambda u_1) \;\; (\lambda > 0) \quad (5)$$

$$\widetilde{M}_1{}^{\lambda} = \left(l_1{}^{\lambda}, m_1{}^{\lambda}, u_1{}^{\lambda}\right) \;\; (\lambda > 0) \quad (6)$$

$$\widetilde{M}_1{}^{-1} = \left(\frac{1}{u_1}, \frac{1}{m_1}, \frac{1}{l_1}\right) \quad (7)$$

$$\widetilde{M}_1 \phi \widetilde{M}_2 = \left(\frac{l_1}{u_2}, \frac{m_1}{m_2}, \frac{u_1}{l_2}\right) \quad (8)$$

$$d(\widetilde{M}_1, \widetilde{M}_2) = \sqrt{\frac{1}{3}[(l_1 - l_2)^2 + (m_1 - m_2)^2 + (u_1 - u_2)^2]} \quad (9)$$

Fuzzy Stepwise Weight Assessment Ratio Analysis (FSWARA) method

Assessing weight of criteria is an important part of almost every multi-criterion problem. Hence, experts have significant contribution in evaluating and prioritizing the weight of criteria. Among wide variety of MCDM approaches, SWARA, have some profound advantages in comparison with other techniques which was introduces by Keršuliene et al. (2010). The SWARA method allows experts or interest groups to estimate the significance of attributes in weight determination, and facilitates discussion and consultation during the assessment process, resulting in increased accuracy compared to other methods (Hosseini Dehshiri, 2025b). Qualitative criteria, non-quantifiable data, incomplete information and inaccessible data all making the decision-making process complicate and uncertain for decision makers. MCDM approaches usually cannot overcome such an ambiguity caused by incomplete information, which makes decision-makers skeptical about their decision's output (Hosseini Dehshiri, 2025a). In this study, Fuzzy SWARA was employed to specify the weight of risks, in order to bridge the existing gap. In this method, assessing weight of criteria follows some steps including (Mavi et al., 2017):

Step (1): Arrange the evaluation criteria in order of expected significance. The confirmed list of determinants of talent turnover in phase 1 should be rank in a descending order by each one of the experts and talents' panel members.

Step (2): Obtaining the comparative importance of criteria ($\tilde{\boldsymbol{S}}_{\boldsymbol{j}}$). In this stage, the paired comparison should be done in order to determine the relative importance of each criterion in comparison with the other most important one. Which is presented as $\tilde{\boldsymbol{S}}_{\boldsymbol{j}}$ in the SWARA method.

Step (3): Calculating Coefficient $\widetilde{\boldsymbol{K}}_{\boldsymbol{j}}$. $\widetilde{\boldsymbol{K}}_{\boldsymbol{j}}$ can be calculated using Eq. (10). It should be mentioned that $\widetilde{\boldsymbol{K}}_{\boldsymbol{j}}$ for the most important criteria must be considered 1.

$$\widetilde{K}_j = \begin{cases} \tilde{1} & j = 1 \\ \tilde{S}_j + \tilde{1} & j > 1 \end{cases} \quad (10)$$

Step (4): Estimating the weight $\tilde{\boldsymbol{q}}_{\boldsymbol{j}}$. Initial weight if criterion can be calculated through Eq.

(11). Similar to Step (3), the weight of the most important criteria must be considered 1. The fuzzy recalculated weight $\tilde{\boldsymbol{q}}_{\boldsymbol{j}}$ is obtained as:

$$\tilde{q}_j = \begin{cases} \tilde{1} & j = 1 \\ \frac{\tilde{q}_{j-1}}{\tilde{K}_j} & j > 1 \end{cases} \tag{11}$$

Step (5): Calculating the normal weights $\tilde{\boldsymbol{w}}_{\boldsymbol{j}}$. Finally, final normal weights of criteria should be calculated which is obtainable by Eq. (12) and then, should be defuzzifying through Eq. (13).

$$\tilde{w}_j = \frac{\tilde{q}_j}{\sum \tilde{q}_j} \tag{12}$$

$$Crisp(\tilde{W}) = \frac{l + 2m + u}{4} \tag{13}$$

According to the stated analysis method, the stages of the research implementation can be summarized as shown in Figure 3. First, by reviewing and reviewing the blockchain literature and the risks of blockchain technology implementation, the initial list of blockchain implementation risks is identified. Then, by forming a decision-making team and having the opinions of experts, the list of blockchain implementation risks in the automotive industry is finalized. In the following, using the statements of the specialists and taking into account the uncertainty in the judgments of experts, the importance of the risks of blockchain implementation in SMEs of component manufacturing is specified. In this regard, it is suggested to use the fuzzy SWARA method to assess the identified risks. Then, the most important risks of blockchain implementation in SMEs are determined, and discussions, conclusions, and theoretical and operational suggestions are presented to eliminate the risks.

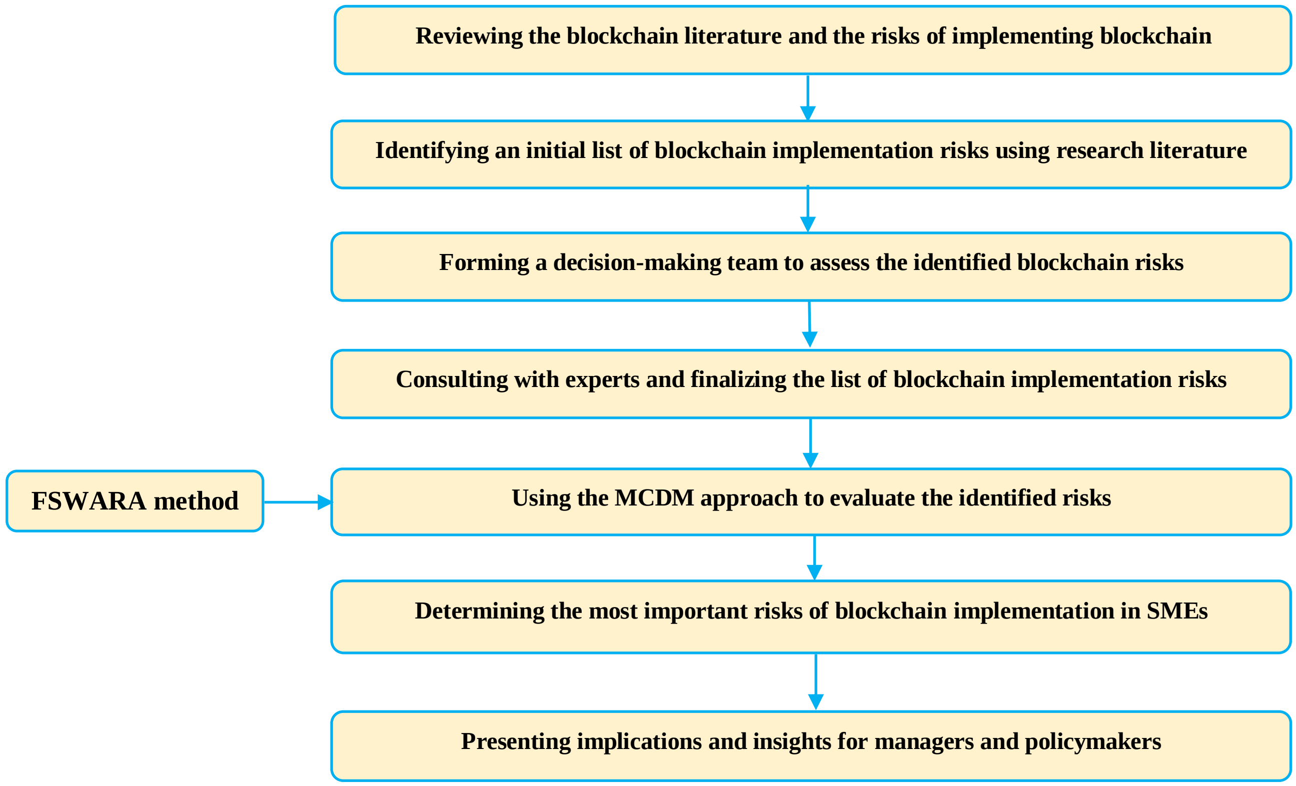

Figure 3. The research stages

Results

In this section, at first, by reviewing the literature and consulting with experts, the blockchain risks in SMEs of the automotive industry are identified. Next, the identified risks are assessed using the FSWARA approach and the degree of importance of the risks is identified. Then, based on the results, discussions, and scientific and practical suggestions are presented.

Case Study

A case study on SMEs in Iran is carried out in this section to examine the use of the recommended methodology and the deployment of blockchain in the automobile industry. SMEs of the automotive industry are one of the key pillars of component production in the automotive industry and cooperate with many domestic and foreign companies. These companies have key internal and external partners to supply raw materials for the production of parts that require the latest technology to improve interactions and partnerships. To improve the tracking of financial transactions, coordination of information, and material, financial, and information flows, it is necessary to use blockchain technology in SMEs. Blockchain with immutability, transparency, reliability, security, tracking, and authentication features improves the performance and cooperation of SMEs in this field. By using blockchain, supply chain visibility, tracking of orders, receipts, payments, and digital assets such as guarantees and licenses are provided in an integrated and transparent manner, and SMEs are able to collaborate with domestic and foreign partners in a more appropriate way. In the implementation of blockchain, there are many challenges and risks that prevent the successful implementation of this technology, and it is required to specify and assess the risks in this area. Therefore, a case investigation is performed on SMEs in the automotive industry in Iran to identify and assess the risks of blockchain implementation. By identifying and assessing the blockchain risks, appropriate solutions to solve the most important challenges and risks are identified and the possibility of successful implementation of blockchain is provided. In this study, MCDM procedures and the opinions of the decision-making team were employed to assess the identified risks. The decision-making team consists of 5 experts with at least ten years of experience in managerial and academic fields in the areas of information technology, supply chain, logistics, software, smart networks, and operations management, who have sufficient knowledge and experience to assess the identified risks due to the comprehensiveness of information and expertise and are selected by targeted sampling. To evaluate blockchain risks, a questionnaire was distributed among the decision-making team's experts, and the average of the opinions in the weighting process is used with the FSWARA method.

Identifying the risks of blockchain implementation on SMEs

At the initial stage, the most significant obstacles and risks associated with implementing blockchain in SMEs were identified through a literature examination. The list of risks that have been found is then modified and finalized after consulting with the experts. The final list of risks associated with blockchain deployment in SMEs in the automotive sector is shown in Table 2.

Table 2. Blockchain risks in SMEs in the automotive industry

Main risk	Sub-risks	Description	Reference
R_1. Organizational	R_{11}. Lack of management support	Successful implementation of blockchain technology requires managerial support for the technology and related changes.	Kim and Kang (2017); Özkan et al. (2020)
	R_{12}. Lack of Skilled employees	To successfully implement the technology, we need an employee with programming skills and a good understanding of the business process.	Almutairi et al. (2022); Böhme et al. (2015); Özkan et al. (2020)
	R_{13}. Lack of necessary infrastructure	Lack of infrastructure and necessary changes to adopt and implement technology causes technology failure.	Almutairi et al. (2022); Kim and Kang (2017); Yadav et al. (2020)

Main risk	Sub-risks	Description	Reference
	R_{14}. Lack of necessary policies and regulations	The lack of comprehensive policies and regulations regarding the use of blockchain, the type of people involved in the blockchain network, and their responsibilities lead to the failure of blockchain implementation.	Almutairi et al. (2022); Kim and Kang (2017); Yadav et al. (2020)
R_2. Security	R_{21}. Cyberattacks	If a malicious person or group hacks the nodes of the blockchain network, the network will face the risks of cyber attacks.	Kim and Kang (2017); Özkan et al. (2020)
	R_{22}. Privacy / confidentiality of information	Data stored in the blockchain network is accessible to all network members and this feature can be limiting when privacy is essential.	Kim and Kang (2017); Zheng et al. (2018)
	R_{23}. Illegal activity/criminal abuse	The abuse of criminals and fraudsters from the vulnerabilities of this technology to penetrate it and carry out illegal activities leads to the failure of blockchain implementation.	Almutairi et al. (2022); Böhme et al. (2015); Özkan et al. (2020)
	R_{24}. Private key security/key .management	If the user forgets his private key, he will not be able to recover it. If the private key is stolen, an individual's account will be vulnerable to manipulation by others. Because the blockchain is not dependent on trusted third-party entities, it will be difficult to track the behavior of criminals and recover modified blockchain data.	Almutairi et al. (2022); Dehshiri et al. (2022); Kim and Kang (2017); Yadav et al. (2020)
R_3. Technical	R_{31}. Irreversibility	This feature acts as a barrier in cases where transaction changes are required.	Böhme et al. (2015); Dehshiri et al. (2022); Kim and Kang (2017)
	R_{32}. Lack of integration with other systems	Blockchain technology is part of the core infrastructure and must work seamlessly with legacy infrastructure. Combining blockchain technology with existing systems is very costly and time-consuming.	Almutairi et al. (2022); Lacity (2018)
	R_{33}. Consensus protocol inefficiency	Each type of consensus algorithm has its advantages and disadvantages. Therefore, the type of consensus protocol should be chosen correctly and based on the need.	Hewa et al. (2021); Litke et al. (2019)
	R_{34}. Poor scalability	The ability to perform thousands of transactions per second is called scalability, and poor scalability means limitations in transaction power and speed.	Almutairi et al. (2022); Hewa et al. (2021); Litke et al. (2019)
R_4. Financial/ commercial	R_{41}. High usage expense	Transferring supply chain information to new systems incurs costs, and the computational expense of replicating transaction records across all nodes in the blockchain network may be a limitation for larger networks.	Böhme et al. (2015); Özkan et al. (2020); Saberi et al. (2019)
	R_{42}. Training cost	Training is needed to inform users about blockchain and how to use it to implement blockchain.	Almutairi et al. (2022); Özkan et al. (2020)

Main risk	Sub-risks	Description	Reference
R_5. Environmental and cultural	R_{51}. Uncertainty of customers	Customer uncertainty due to a low level of knowledge and lack of trust in the technology can affect blockchain adoption.	Janssen et al. (2020); Özkan et al. (2020); Saberi et al. (2019)
	R_{52}. Lack of industry involvement in blockchain adoption	The lack of industry leadership in supply chain and blockchain technology practices is contributing to the failure of this technology.	Kouhizadeh et al. (2021); Saberi et al. (2019)
	R53. Non-acceptance of legal authorities (government) and lack of regulatory laws	The decentralized nature of blockchain can limit control and governance by regulatory agencies, potentially leading to non-acceptance by legal institutions and a lack of appropriate government regulatory legislation to support the technology.	Kouhizadeh et al. (2021); Litke et al. (2019)
	R_{54}. Problems in cooperation, communication, and coordination among chain members	Lack of cooperation, communication, and coordination between supply chain partners with different and sometimes conflicting motivations/objectives and operational priorities and other reasons that prevent cooperation.	Kouhizadeh et al. (2021); Saberi et al. (2019)

Specifying the importance of blockchain risks with the FSWARA method

In this section, weighting and specifying the importance of the risks of blockchain in SMEs in the automotive industry are discussed using the FSWARA method. Specialists are requested to classify the main risks identified in descending order of importance, as part of the first step of FSWARA's method. The comparative significance of each risk is determined and the initial weight of the risks is measured, following the stages of the FSWARA method. Following normalizing the weights of the primary risks, the final weight of the risks is determined and presented in Table 3.

Table 3. Calculating the significance of risks

Main risks	Comparative importance of criteria $\tilde{S}_j$			Calculating $\tilde{K}_j$			Initial weight $\tilde{q}_j$			$\tilde{w}_j$		
R_2	-	-	-	1.000	1.000	1.000	1.000	1.000	1.000	0.318	0.339	0.365
R_3	0.286	0.333	0.400	1.286	1.333	1.400	0.714	0.750	0.778	0.227	0.254	0.284
R_1	0.222	0.250	0.286	1.222	1.250	1.286	0.555	0.600	0.636	0.177	0.203	0.233
R_5	0.400	0.500	0.667	1.400	1.500	1.667	0.333	0.400	0.455	0.106	0.136	0.166
R_4	0.667	1.000	1.500	1.667	2.000	2.500	0.133	0.200	0.273	0.042	0.068	0.100

The main risks associated with implementing blockchain in SMEs in the automotive industry were weighted, and the outcomes indicated that security (R_2), technical (R_3), and organizational (R_1) risks were the most significant, in that order.

In the following, the risks related to each of the main risks are assessed and weighted based on the stages of the FSWARA method. First, organizational sub-risks are weighted, and the results are presented in Table 4.

Table 4. The significance of organizational sub-risks

Sub-risks	Comparative importance of criteria $\tilde{S}_j$			Calculating $\tilde{K}_j$			Initial weight $\tilde{q}_j$			Weight $\tilde{w}_j$			Final weight			Crisp weight
R_{14}	-	-	-	1.000	1.000	1.000	1.000	1.000	1.000	0.360	0.396	0.419	0.114	0.081	0.098	0.093
R_{13}	0.220	0.320	0.400	1.220	1.320	1.400	0.714	0.758	0.820	0.257	0.300	0.344	0.082	0.061	0.080	0.071
R_{12}	0.600	0.800	0.900	1.600	1.800	1.900	0.376	0.421	0.512	0.135	0.167	0.215	0.043	0.034	0.050	0.040
R_{11}	0.140	0.220	0.280	1.140	1.220	1.280	0.294	0.345	0.449	0.106	0.137	0.189	0.034	0.028	0.044	0.033

The results showed that among the organizational sub-risks, the sub-risks of lack of necessary policies and regulations (R_{14}), lack of necessary infrastructure (R_{13}), and lack of skilled employees (R_{12}) were respectively introduced as the most important organizational sub-risks. In the following, the security sub-risks are evaluated using the FSWARA approach. The findings of computing the weight of security sub-risks are shown in Table 5.

Table 5. The significance of security sub-risks

Sub-risks	Comparative importance of criteria $\tilde{S}_j$			Calculating $\tilde{K}_j$			Initial weight $\tilde{q}_j$			Weight $\tilde{w}_j$			Final weight			Crisp weight
R_{22}	-	-	-	1.000	1.000	1.000	1.000	1.000	1.000	0.338	0.356	0.385	0.108	0.121	0.141	0.122
R_{21}	0.280	0.320	0.380	1.280	1.320	1.380	0.725	0.758	0.781	0.245	0.270	0.301	0.078	0.092	0.110	0.093
R_{24}	0.220	0.290	0.420	1.220	1.290	1.420	0.510	0.587	0.640	0.172	0.209	0.246	0.055	0.071	0.090	0.072
R_{23}	0.190	0.274	0.400	1.190	1.274	1.400	0.365	0.461	0.538	0.123	0.164	0.207	0.039	0.056	0.076	0.057

The results indicated that the sub-risks of privacy/confidentiality of information (R_{22}), cyber-attacks (R_{21}), and private key security/key management (R_{24}) were recognized as the most important obstacles in the security-related risk. At this stage, the technical sub-risks are also evaluated based on the steps of the FSWARA method, and the outcomes related to the importance of each of the technical sub-risks are presented in Table 6.

Table 6. The significance of technical sub-risks

Sub-risks	Comparative importance of criteria $\tilde{S}_j$			Calculating $\tilde{K}_j$			Initial weight $\tilde{q}_j$			Weight $\tilde{w}_j$			Final weight			Crisp weight
R_{34}	-	-	-	1.000	1.000	1.000	1.000	1.000	1.000	0.327	0.346	0.379	0.074	0.088	0.108	0.089
R_{31}	0.250	0.300	0.410	1.250	1.300	1.410	0.709	0.769	0.800	0.232	0.266	0.303	0.053	0.068	0.086	0.069
R_{33}	0.190	0.250	0.350	1.190	1.250	1.350	0.525	0.615	0.672	0.172	0.213	0.255	0.039	0.054	0.072	0.055
R_{32}	0.140	0.220	0.300	1.140	1.220	1.300	0.404	0.504	0.590	0.132	0.175	0.223	0.030	0.044	0.064	0.046

The weighting results of technical sub-risks indicate the importance of sub-risks of poor scalability (R_{34}), irreversibility (R_{31}), and consensus protocol inefficiency (R_{33}) respectively. Next, the financial/commercial sub-risks are assessed based on the proposed approach. Table 7 displays the findings of the assessment of the significance of financial and commercial sub-risks.

Table 7. The significance of financial/commercial sub-risks

Sub-risks	Comparative importance of criteria $\tilde{S}_j$			Calculating $\tilde{K}_j$			Initial weight $\tilde{q}_j$			Weight $\tilde{w}_j$			Final weight			Crisp weight
R_{41}	-	-	-	1.000	1.000	1.000	1.000	1.000	1.000	0.552	0.559	0.571	0.023	0.038	0.057	0.039
R_{42}	0.230	0.270	0.330	1.230	1.270	1.330	0.752	0.787	0.813	0.415	0.441	0.464	0.018	0.030	0.046	0.031

The weighting results of the financial/commercial sub-risks show the order of priority of the sub-risks of high usage expense (R_{41}) and training cost (R_{42}). Finally, the environmental/cultural sub-risks for blockchain implementation are evaluated, and the evaluation results are displayed in Table 8.

Table 8. The significance of environmental/cultural sub-risks

Sub-risks	Comparative importance of criteria $\tilde{S}_j$			Calculating $\tilde{K}_j$			Initial weight $\tilde{q}_j$			Weight $\tilde{w}_j$			Final weight			Crisp weight
R_{53}	-	-	-	1.000	1.000	1.000	1.000	1.000	1.000	0.317	0.337	0.356	0.034	0.046	0.059	0.046
R_{51}	0.170	0.230	0.290	1.170	1.230	1.290	0.775	0.813	0.855	0.246	0.274	0.304	0.026	0.037	0.051	0.038
R_{54}	0.210	0.280	0.330	1.210	1.280	1.330	0.583	0.635	0.706	0.185	0.214	0.251	0.020	0.029	0.042	0.030
R_{52}	0.190	0.220	0.290	1.190	1.220	1.290	0.452	0.521	0.594	0.143	0.175	0.211	0.015	0.024	0.035	0.024

The findings of the weighting of environmental/cultural sub-risks indicate that the sub-risks of non-acceptance of legal authorities (government) and lack of regulatory laws (R_{53}), uncertainty of customers (R_{51}), and problems in cooperation, communication, and coordination among chain members (R_{54}) are respectively of the greatest importance. Figure 4 displays the findings of the comparison of the relative weights of the sub-risks associated with the application of blockchain in the supply chain of SMEs.

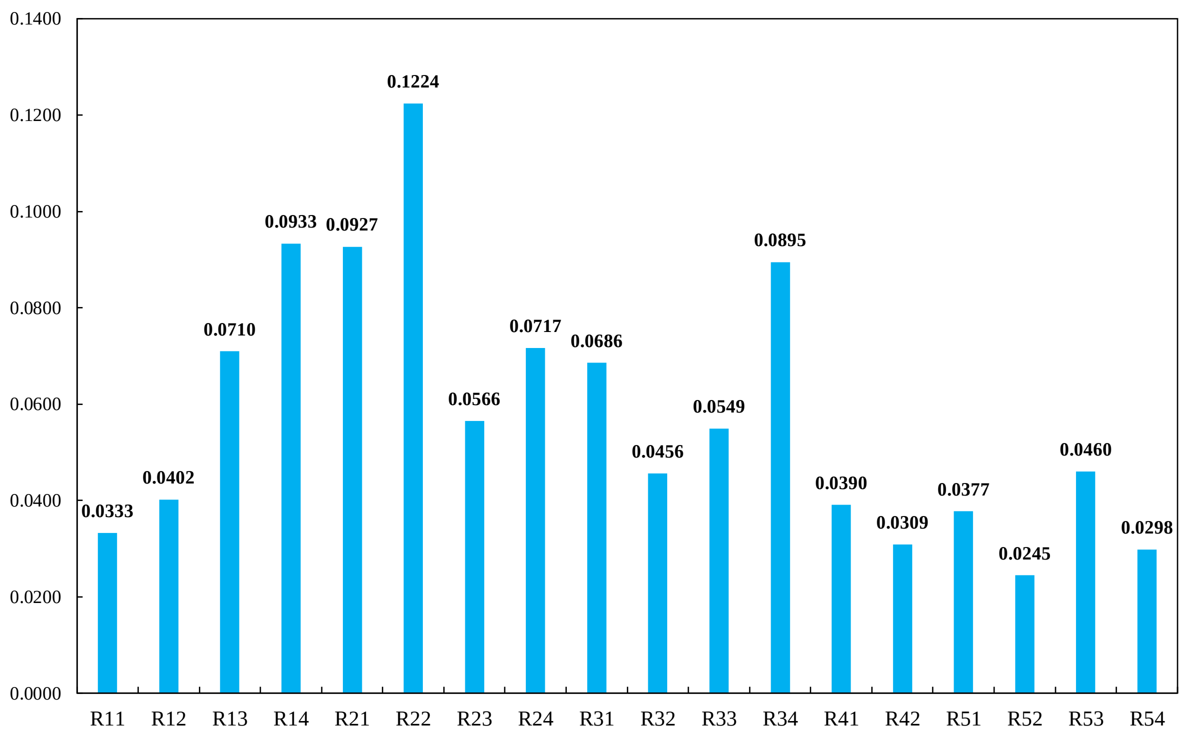

Figure 4. Comparing the significance of the sub-risks of blockchain in SMEs

The findings indicate that sub-risks R_{22}, R_{14}, and R_{21} were introduced as the most significance sub-risks with values of 0.1224, 0.0933, and 0.0927 respectively.

Discussion

Using blockchain is currently expanding quickly, and because of its many advantages, many governments and businesses are looking at ways to apply and incorporate it into their systems. Productivity gains and effective supply chain management are possible outcomes of integrating blockchain technology with SMEs' supply chains. However, blockchain adoption comes with risks that must be properly managed to achieve a competitive blockchain-based supply chain management framework. In this research, using the FSWARA technique as one of the groups MCDM methods, 18 risks of blockchain implementation in the SMEs of the automotive sector were identified. The identified risks were in five organizational, security, technical, financial, and environmental fields, and using the FSWARA technique, the relative importance of each of the risks and sub-risks was calculated. The study identified security, technical, and organizational risks as the most significant risks, and poor scalability, information privacy/confidentiality, and cyber-attacks as the most significant sub-risks.

Scalability is a significant challenge facing the growth of blockchain technology, which is also the most important risk for the research company. The current block size and time interval used to create a new block limit the blockchain's ability to meet the high demand for real-time processing of millions of transactions. To address this issue, various solutions have been proposed, including a new cryptocurrency scheme that optimizes blockchain storage by deleting old transaction records and using an account tree database to track balances. Another solution is the next generation of blockchain, known as Bitcoin-NG, which improves transaction power and reduces delays without changing the network's architecture and trust model.

One of the main challenges in using blockchain in the logistics industry is data privacy and confidentiality. Although security, storage and management of information are the main features of blockchain, privacy is still a challenge. In the supply chain, blockchain is used to store data, but the irreversibility and transparency of the blockchain may be unsuitable for sensitive data. For example, auto parts manufacturers may track information about their suppliers, which could include inventory, unit cost, or bill of materials. This issue can increase the bargaining power of the minority at the top of the supply chain and put suppliers in different layers of the supply chain under pressure to reduce prices and harm healthy competition. Therefore, it is essential that blockchains are designed in such a way that users' privacy is protected without affecting other features of the blockchain. Also, another important security risk in using blockchain is cyber-attacks. Even though the blockchain network is highly secure and its data is encrypted, it is still susceptible to hacking and cyberattacks if several individuals have access to it. As a result, security and control solutions are required to enhance security and manage access to the blockchain network. Additionally, vendors, trusted partners, and internal corporate personnel may make mistakes, therefore it is important to keep an eye on their access to the blockchain network.

Organizational risks include internal elements and factors of the organization. In the use of blockchain technology, one of the basic challenges is establishing the necessary laws and regulations for its use and also providing the necessary infrastructure for its implementation. In fact, the main organizational risk is the lack of laws and policies necessary to use blockchain. For the successful implementation of this technology and its widespread use, it is necessary to create appropriate laws and regulations that are coordinated with the changes in technology. Another organizational risk is the non-availability of the necessary infrastructure for blockchain implementation. However, this risk is not a challenge for this company; Because the company is in the field of skilled employees and management support, and its management supports business change and new technologies. In fact, management support is a key factor in the successful implementation of any supply chain operation.

In the discussion of security risks, privacy protection and dealing with cyber-attacks have been discussed as the most important security risks. But another important security risk is key management, which ranks third among the company's security risks. In the blockchain, transaction records are recorded immutably, and no damage to past transactions is possible. However, if private keys are stolen or lost, data and digital assets can be stolen. The lack of a central controller in the blockchain aggravates this issue; Therefore, it is essential to use proper key management methods in the company.

Blockchain's immaturity causes technical challenges. One of these challenges is the issue of scalability and mismatch with the amount of demand, which was mentioned in the previous paragraph. The risk of immutability is one of the main technical challenges of blockchain, and it is completely preferable to the other two technical challenges, i.e., the issue of scalability and security. Immutability means the integrity of the information in the blockchain, which guarantees the reliability and accuracy of the information. However, immutability means that previous data and errors are permanently recorded in the transaction records, and even if new data is added to the block chain for modification, the previous data is not changed or deleted. For example, a record of a mistake in manufacturing a poor part can exist forever.

Another challenge of blockchain is its integration with other systems in the company. This challenge ranks third in the importance of technical risks. The challenge of inefficiency of the consensus protocol is another technical risk that to update the blockchain network, a number of cryptographic protocols are used to achieve consensus among the nodes participating in the blockchain. Each of these protocols should be evaluated according to the framework used and the requirements of the network members. In the present company, the proof-of-work protocol is used for consensus. The advantage of this method is to help democratize the overall agreement between network participants; But in this protocol, a group of members may agree to mine the next block privately, which will create a custom chain and eventually attack the network. This leads to a loss of trust in the supply chain and in the brand's consumers. Other consensus protocols also have their own advantages and disadvantages. Today, there are various consensus mechanisms for updating the blockchain network; But more research is still needed to find algorithms that are flexible enough to support a wide variety of applications.

Among the financial and business risks, the high cost of using blockchain is an important challenge. To use blockchain, you need to invest in several hardware and software, which entails high costs. In addition, with the implementation of technology, there are also side costs such as costs related to the reconfiguration of the organization's processes. However, the studied company does not have a challenge in the field of training costs to increase the knowledge of employees due to the management policy of using dynamic and expert forces. This policy reduces the costs related to employment, quality improvement and productivity, and as a result, it has various financial effects.

Environmental and cultural risks include risks related to the regulatory environment, industry characteristics, customers, and relationships between companies. One of the most important environmental risks is the non-acceptance of government authorities and the lack of necessary regulations. These regulations prevent the implementation of blockchain due to the newness. Therefore, it is inevitable and vital to regard the legal aspects of business and comply with government laws and regulations. The risk of customer uncertainty is another important environmental risk. In this regard, increasing awareness and empowering consumers to accept new technology is essential. In the studied company, there is an effective communication between the members of the chain and the cultural differences are very few due to the locality of the members. Therefore, the company does not have much risk in terms of cooperation and coordination between supply chain members. Also, due to the automotive industry's support for new technologies, the company has no challenge in the field of industrial support. However, government and industry should work together to develop common standards and rules to resolve data sharing issues while respecting privacy.

The findings were compatible with the outcomes of some other research. For example, Sanka et al. (2021), Drljevic et al. (2020), and Zheng et al. (2018) have identified the risk of scalability and privacy as the most important risks of blockchain. Also, Saberi et al. (2019) have also introduced the risk of scalability as one of the important risks of blockchain. In the study of Kouhizadeh et al. (2021), the most important risks and challenges were issues related to information security, immaturity of technology, negative image of technology, lack of understanding of customers about blockchain, and lack of coordination and cooperation among partners. However, in the present research, the risk of non-cooperation and coordination among supply chain partners was of low importance due to the existence of supply chain network members with effective cooperation. In addition, Dutta et al. (2020) in addition to maintaining privacy and scalability, have also introduced the risk of lack of necessary laws and regulations in the field of blockchain as one of the most important risks of blockchain. In this work, this risk is also recognized as one of the important organizational risks, but due to the support of the senior manager of technology and the presence of skilled employees, fewer problems arise for the company than security and technical risks such as scalability and privacy protection; Therefore, it has a lower priority. In the research of Litke et al. (2019), scalability, consensus mechanism and privacy protection have been introduced as the most important risks in the path of blockchain. In the current research, the risk related to the consensus mechanism faces a lower risk due to the selection of the proof-of-work consensus that is suitable for implementation in the supply chain of the mentioned company.

Conclusion

This study aimed to examine the effectiveness of blockchain in the supply chain of SMEs in the automotive industry. Through a review of the literature and expert consultations, the study identified 18 risks associated with implementing blockchain. Then, using the MCDM method and the SWARA method based on fuzzy numbers and considering the uncertainty in the judgment of experts, the weight of each risk was determined. The findings displayed that among the main risks, security, technical and organizational risks were the most important. Also, among the sub-risks, the sub-risks of privacy/confidentiality of information (R22), lack of necessary policies and regulations (R14), and cyber-attacks (R21) were identified as the most important sub-risks with values of 0.1224, 0.0933 and 0.0927, respectively. According to the discussions presented, the results of this research help company managers to identify the risks of blockchain technology and their order of priority in their company and, considering the limitation of financial and time resources, focus their efforts on important and priority sectors and plan to eliminate these risks based on the points described in the analysis of the results of important risks of concern to the company. Due to the transformative nature of blockchain, risk assessment and management are very important in the field of business transformation. However, research on blockchain risk management is still in its infancy, and more research is needed in this area. To improve the process of blockchain development, future research should focus on blockchain risks in other industrial sectors, new challenges that arise at the same time as blockchain changes, providing solutions and prioritizing solutions for effective and more efficient risk management. Also, further study on the potential policies and legal implications of blockchain development, infrastructure challenges in developing countries, high costs of data storage with very low latency in processing transactions, scalability, and optimization of the consensus mechanism in blockchain are suggested.

The research recommendations can be as follows: In order to accurately categorize risk indicators and sub-indices, in future research, exploratory factor analysis approaches can be used and confirm the tree of risk indicators and sub-indices using confirmatory factor analysis or fuzzy Delphi methods. Also, the investigation of blockchain risks in other industries such as energy and food industries has been done using circular economy indicators, and more research in this field is suggested. Due to the existence of cause-effect relationships between the investigated risks, it is suggested to use methods such as DEMATEL or ANP to specify the significance of factors regarding these relationships. Also, in the next research, it is suggested to develop new MCDM methods and take into account various types of mixed uncertainty including rough numbers, distance fuzzy numbers, and Z-numbers in the context of evaluating blockchain solutions and risks.

Data Availability Statement

Data available on request from the authors.

Acknowledgements

The authors gratefully acknowledge the management and data analytics team for providing access to the empirical data used in this study.

Conflict of interest

The authors declare no conflict of interest related to the content, data, or results of this study. All analyses were conducted independently, and no external parties influenced the interpretation or presentation of the findings.

Funding

The authors received no financial support for this article's research, authorship, and/or publication.

Ethical considerations

The authors declare compliance with all applicable ethical guidelines, including proper data handling, originality of content, and avoidance of duplicate submission.

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