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Risk Assessment of Digital Technologies in Sustainable Supply Chain Management: A Fuzzy VIKOR Method †

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Abstract: In recent years, digital technologies have emerged as a key driver of intelligence and visibility in supply chain management, offering companies a competitive edge to enhance sustainability. Despite the various benefits, digitalization introduces risks to supply chain sustainability. This paper aims to assess and prioritize these risks using a multi-criteria decision-making method (Fuzzy-VIKOR approach). Drawing from existing literature, criteria, alternatives (risks), and a decision matrix are established. The findings reveal that the risk of a lack of qualifications in information technology skills is the most critical among 12 factors, significantly impacting sustainability performance indicators. This novel approach contributes a fresh perspective to the literature on the risk assessment of digitalization in supply chain sustainability.

Keywords: digitalization; risk assessment; sustainability; Fuzzy VIKOR method

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1. Introduction

Over the last decade, there has been significant growth in sustainability and digitalization within supply chain management [1]. Sustainable practices are needed worldwide because of the depletion of natural resources and the state of the ecosystem [2]. Sustainability is the responsible management of the effect of actions on society and the environment, focusing on minimizing negative effects and promoting positive contributions. Digital technologies can bring transparency and intelligence to supply chains, which leads to more efficiency, but they may have separate goals from sustainability, and their strategies do not align with each other [3].

Digital transformation is important for companies in modernizing supply chains, addressing supply chain risks, and reducing inefficiencies [4]. These technologies can also offer a wide range of sustainability benefits, including waste reduction, energy conservation, and recycling opportunities [5]. However, they can introduce new challenges in sustainability [3]. Although digital technologies are frequently embraced to mitigate supply chain risks, their application introduces new challenges [6]. While data-driven technologies are essential for sustainable supply chain management (SSCM), they bring risks such as data security issues [7].

As supply chains become more complex and digitally driven, effective risk management is crucial [8]. The risk associated with digital supply chain systems can be due to uncertainties in technological changes and potential negative outcomes arising from the strategic behaviors of supply chain partners [9]. While current literature tends to focus on the positive impacts of digital technologies, there is limited attention given to evaluating the risks they may introduce to supply chain operations [6]. Addressing and mitigating these risks is crucial for fully realizing the opportunities presented by digitalization for businesses and consumers [10].

In this paper, the literature review related to risk assessment, digitalization, and supply chain sustainability is performed to identify potential risks that can be caused by digital technologies in SSCM. Then, the risks that are found through the literature review will be evaluated for every sustainability dimension, including environmental, social, and economic dimensions. Following existing literature, a blended approach utilizing both the SWARA and TODIM methods in multi-criteria decision-making (MCDM) is employed to assess the risks associated with the digitization process and the sustainability of the supply chain [7]. This study will introduce a fuzzy VIKOR method for decision-making under uncertainty to evaluate the potential risks. Accordingly, there are two questions:

1. What are the risks that can be brought to supply chain sustainability by digitalization?
2. How will the prioritization of these risks be determined based on the fuzzy VIKOR method?

After the introduction, this study includes these following steps: Section 2 focuses on the literature review; Section 3 represents the research methodology; the case study of this research will be detailed in Section 4; and Section 5 covers the conclusion of this study.

2. Literature Review

2.1. Digital Supply Chain

In recent years, companies have been looking for opportunities to make their supply chains efficient and responsive [11]. Hence, industries are extensively employing emerging technologies such as the Internet of Things (IoT), cloud services, and artificial intelligence to improve the efficiency of their supply chain operations [6]. Digital supply chain management uses these up-to-date technologies to provide a clear insight into supply chain stages and link supply chain participants together [12]. Digital technologies can provide efficiency, visibility, resilience, and robustness. They can also help supply chains to reduce their risks and uncertainties [13]. Digitization introduces great benefits for supply chains, including real-time data collection, better information availability, and improved supply-chain management practices. Therefore, supply chains can take advantage of these benefits and minimize their bullwhip effect [14]. Although digitalization can bring different benefits to the supply chain, it is also associated with new risks, such as data security risks, and it can make the industry more vulnerable [6].

2.2. Sustainable Supply Chain Management

Economics has been the focus of the supply chain, but recently, the emphasis has shifted to social and environmental issues as well, and sustainability has emerged as a crucial concern in the realm of supply chain management [15]. Additionally, the dramatic increase in demand for resources highlights the importance of sustainability [12]. Sustainable supply chain management involves aligning the goals of the supply chain with sustainability objectives and employing the Triple Bottom Line (TBL) thinking in the process [14]. Based on the TBL, managers should consider environmental, social, and economic aspects when deciding about their supply chains [3]. The TBL is important for measuring a company's success by considering its contribution to sustainability goals, as well as addressing important global issues such as poverty elimination, climate change, etc. [16]. Manufacturers are increasingly adopting sustainability measures since they provide a competitive advantage, are cost-saving because of being energy efficient, and can enhance a business' reputation and build public trust [17]. Moreover, sustainability practices can bring an improvement to supply chain performance, labor satisfaction, and better financial status [11].

2.3. Risk Assessment of Digitalization in Sustainable Supply Chain Management

Digitalization has positive impacts on sustainability such as waste reduction, energy conservation, and recycling opportunities [5]. The focus of digitalization is mainly on transparency and the visibility of data through the supply chain, whereas sustainability emphasizes the social, economic, and environmental aspects [3]. It can be seen that the focus of earlier literature has mainly been on the advantages of digitalization, while there is a lack of risk assessment. Hence, it is essential to develop a comprehensive assessment of supply chain risks arising from digital technologies to effectively reduce and mitigate emerging risks in operations management [6]. In [7], 12 risk factors are identified through the literature review, which include the following: R1: data security; R2: inadequate training in managing data; R3: complex data; R4: weak IT systems and infrastructure; R5: lack of certainty in government policies regarding data management; R6: resource risks; R7: insufficient return on investment related to IT systems; R8: lack of IT skills; R9: data privacy; R10: lack of communication between parties; R:11 high energy usage of IT systems; and R12: the risk of employees not accepting new technologies. A hybrid MCDM approach that combines SWARA and TODIM methods is used in [7] to prioritize the risks considering three criteria, which are "Economic", "Social", and "Environmental" aspects of sustainability. "Technological advancement" and "Performance management" are also vital performance indicators regarding sustainability [18].

2.4. Fuzzy VIKOR Method

The VIKOR method is a compromise-based multi-criteria decision-making (MCDM) approach that has been widely applied in various fields. Ref. [19] integrated the fuzzy analytic hierarchy process (F-AHP) and fuzzy VIKOR to evaluate and rank influenza intervention strategies. Ref. [20] utilized the fuzzy VIKOR method for the selection of rapid prototyping technologies in an agile environment. Furthermore, ref. [21] extended the VIKOR method to solve MCDM with a bipolar fuzzy environment, showcasing the adaptability and flexibility of the method. The fuzzy VIKOR method has also been compared with other MCDM methods. Ref. [22] compared fuzzy VIKOR with other tools and observed consistent results with slight differences, demonstrating its effectiveness in the decision-making processes. Moreover, ref. [23] presented a comparative analysis of results by fuzzy VIKOR and modified fuzzy VIKOR methods, emphasizing their applicability and adaptability across different contexts. Furthermore, the integration of fuzzy VIKOR with other methods has been explored. Ref. [24] integrated fuzzy VIKOR with other MCDM methods to improve project portfolio selection processes under uncertainty in pharmaceutical companies. Ref. [25] exploited a hybrid multi-criteria method using the fuzzy analytic hierarchy process (FAHP) and fuzzy VIKOR for third-party logistics selection in sustainable supply chains, showcasing its versatility in addressing sustainability aspects.

3. Methodology

This section provides an overview of the fuzzy VIKOR method employed in this research. The fuzzy VIKOR approach for risk assessment of digital technologies in sustainable supply chain management includes the following steps:

1. Identifying the decision-making goal and finding the problem scope.

In this paper, the goal is to evaluate the potential risks that digital technologies used in sustainable supply chain management can cause. Based on the literature review, only a few studies addressed the risks related to digitalization and sustainability. This decision-making model is developed to assess digitalization risks under uncertainty.

2. Decision maker selection and defining the criteria and alternatives.
3. Identifying linguistic variables.

Linguistic variables are specified for the weight of criteria and the fuzzy number of alternatives according to the criteria. These linguistic variables can be seen in Figure 1. They are used to evaluate the importance of criteria and rate the alternatives [26].

4. Generating a decision matrix with fuzzy logic by considering the perspectives of decision makers.

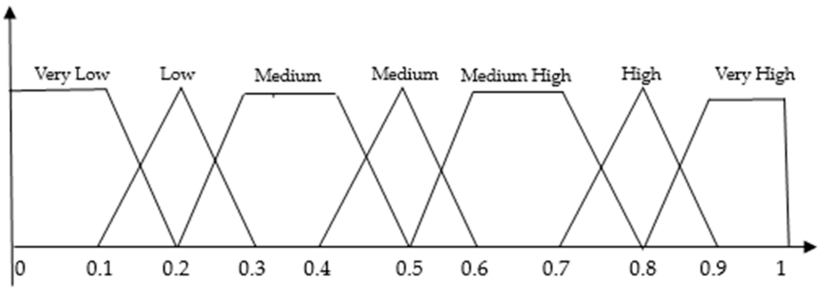

Figure 1. Linguistic variables.

Considering k decision makers, the aggregate fuzzy rating $(\tilde{x_{ij}})$ of the alternatives with respect to criteria can be found based on following equation:

$$\tilde{x_{ij}} = (x_{ij1},\ x_{ij2},\ x_{ij3},\ x_{ij4}) \tag{1}$$

where

$x_{ij1} = \min\{x_{ij1}\}_k$;
$x_{ij2} = \frac{1}{K}\sum_{k=1}^{K} x_{ij2k}$, $x_{ij3} = \frac{1}{K}\sum_{k=1}^{K} x_{ij3k}$;
$x_{ij4} = \max\{x_{ij4}\}_k$.
Then, the aggregated fuzzy weights of criteria can be found in the equations above.

5. Converting the fuzzy decision matrix and fuzzy weights into non-fuzzy values through the process of defuzzification.
6. Finding the best (f_j^*) and the worst (f_j^-) values of each criterion in deffuzzified matrix.

$$f_j^* = max_i\ (x_{ij}),\ f_j^- = min_i\ (x_{ij}) \tag{2}$$

7. Calculating the values of S_i (maximum group utility) and R_i (minimum individual regret), where (i = 1, 2, ..., m):

$$S_i = \sum_{i=1}^{n} w_i(f_i^* - f_{ij}) / (f_i^* - f_i^-) \tag{3}$$

$$R_i = \max_i w_i(f_i^* - f_{ij}) / (f_i^* - f_i^-) \tag{4}$$

8. Calculating Q_i by using the values of S_i and R_i (i = 1, 2, ..., m):

$$Q_i = \nu\frac{S_i - S^*}{S^- - S^*} + (1-\nu)\left(\frac{R_i - R^*}{R^- - R^*}\right) \tag{5}$$

In this equation, $S^- = \max_i S_i$, $S^* = \min_i S_i$, $R^- = \max_i R_i$, $R^* = \min_i R_i$. Moreover, ν is the weight of maximum group utility, $(1-\nu)$ is the weight of the individual regret. In this study, ν is assumed to be equal to 0.5, and $(1-\nu)$ is also equal to 0.5.

9. Ranking the alternatives by sorting the values of S_i, R_i, and Q_i in ascending order.
10. Checking the acceptable advantage and acceptable stability of the decision.

If Q (A^1) is the first position in the ranking, it will be considered to have an acceptable advantage, while Q (A^2) − Q (A^1) $\geq \frac{1}{n-1}$. In this equation, Q (A^2) is the second position in the ranking, and n represents the number of alternatives (risks). Q (A^1) has acceptable stability if it is ranked as the best solution in S_i and R_i.

4. Case Study

The suggested approach is employed to evaluate the risk associated with digital technologies in the context of sustainable supply chain management. The required criteria and alternatives (risks) were found through the literature review. Then, three experts were asked to evaluate the risks regarding criteria and give weight to each criterion. These experts were a technical and IT support manager, a production manager, and a R&D manager who work in the largest IT company in Iran. The company was founded in 1985, provides software and IT solutions for more than 85,000 customers in Iran, and it has more than 1700 employees.

The decision makers' evaluations, based on the linguistic variables depicted in Figure 1 for criteria weights, are showcased in Table 1. Subsequently, the ratings of the risk factors concerning the criteria are evaluated using linguistic variables and are presented in Table 2. The assessment of risk factors and criteria weights in linguistics is transformed into trapezoidal fuzzy numbers through the application of Equation (1), as illustrated in Table 3. Once the aggregated fuzzy matrix is obtained, the crisp values of fuzzy sets are established. Subsequently, the optimal and least values for criteria are identified, as detailed in Table 4. Finally, the values of S_i, R_i, and Q_i are calculated using Equations (3)–(5). The results of these calculations, along with the ranking of risk factors, are presented in Table 5.

Table 1. Weights of criteria based on decision makers.

	Criteria				
Decision Maker	**Social**	**Economic**	**Environmental**	**Technological Advancement**	**Performance Management**
DM1	M	M	L	H	M
DM2	M	M	H	M	L
DM3	M	M	L	M	H

Table 2. Rating of 12 risk factors by decision makers with regard to the criteria.

		Criteria				
	Alternatives	**Social**	**Economic**	**Environmental**	**Technological**	**Performance**
DM1	R1	ML	H	VL	M	M
	R2	M	M	L	H	VH
	R3	M	H	M	VH	H
	R4	H	M	L	H	H
	R5	M	H	M	H	VH
	R6	VL	VH	L	M	H
	R7	H	VH	M	M	H
	R8	VL	H	M	H	VH
	R9	H	VH	L	M	M
	R10	M	H	M	M	H
	R11	M	L	M	H	MH
	R12	VH	H	H	M	H
DM2	R1	H	H	L	H	H
	R2	M	M	ML	M	H
	R3	L	M	L	MH	MH
	R4	M	H	VL	H	H
	R5	M	M	L	M	M
	R6	L	M	M	M	H
	R7	L	M	L	M	M
	R8	H	H	L	H	H
	R9	H	H	L	M	H
	R10	M	H	L	H	H
	R11	M	M	H	M	M
	R12	M	H	M	M	M

Table 2. *Cont.*

	Criteria					
	Alternatives	**Social**	**Economic**	**Environmental**	**Technological**	**Performance**
DM3	R1	VL	VH	ML	M	M
	R2	M	H	VL	VH	VH
	R3	L	M	M	H	H
	R4	M	M	L	MH	VH
	R5	H	L	M	H	H
	R6	L	VH	L	M	H
	R7	VH	H	M	M	VH
	R8	L	M	L	H	H
	R9	M	H	M	M	M
	R10	L	VH	M	M	H
	R11	H	VL	H	H	H
	R12	H	M	M	M	H

Table 3. Aggregated fuzzy weights of the criteria and the ranking of one alternative.

	Criteria				
Weights	(0.4, 0.5, 0.5, 0.6)	(0.4, 0.5, 0.5, 0.6)	(0.1, 0.37, 0.47, 0.9)	(0.4, 0.57, 0.6, 0.9)	(0.1, 0.47, 0.53, 0.9)
Alternatives	Social	Economic	Environmental	Technological	Performance
R1	(0, 0.37, 0.43, 0.9)	(0.7, 0.83, 0.87, 1)	(0, 0.17, 0.23, 0.5)	(0.4, 0.6, 0.6, 0.9)	(0.4, 0.6, 0.6, 0.9)
R2	(0.4, 0.5, 0.5, 0.6)	(0.4, 0.6, 0.6, 0.9)	(0, 0.17, 0.23, 0.5)	(0.4, 0.73, 0.77, 1)	(0.7, 0.87, 0.93, 1)
R3	(0.1, 0.3, 0.3, 0.6)	(0.4, 0.6, 0.6, 0.9)	(0.1, 0.4, 0.4, 0.6)	(0.5, 0.77, 0.83, 1)	(0.5, 0.73, 0.77, 0.9)
R4	(0.4, 0.6, 0.6, 0.9)	(0.4, 0.6, 0.6, 0.9)	(0, 0.13, 0.17, 0.3)	(0.5, 0.73, 0.77, 0.9)	(0.7, 0.83, 0.87, 1)
R5	(0.4, 0.6, 0.6, 0.9)	(0.1, 0.5, 0.5, 0.9)	(0.1, 0.4, 0.4, 0.6)	(0.4, 0.7, 0.7, 0.9)	(0.4, 0.73, 0.77, 1)
R6	(0, 0.13, 0.17, 0.3)	(0.4, 0.77, 0.83, 1)	(0.1, 0.3, 0.3, 0.6)	(0.4, 0.5, 0.5, 0.6)	(0.7, 0.8, 0.8, 0.9)
R7	(0.1, 0.63, 0.67, 1)	(0.4, 0.73, 0.77, 1)	(0.1, 0.3, 0.3, 0.6)	(0.4, 0.5, 0.5, 0.6)	(0.4, 0.73, 0.77, 1)
R8	(0, 0.33, 0.37, 0.9)	(0.4, 0.7, 0.7, 0.9)	(0.1, 0.3, 0.3, 0.6)	(0.7, 0.8, 0.8, 0.9)	(0.7, 0.83, 0.87, 1)
R9	(0.4, 0.7, 0.7, 0.9)	(0.7, 0.83, 0.87, 1)	(0.1, 0.3, 0.3, 0.6)	(0.4, 0.5, 0.5, 0.6)	(0.4, 0.6, 0.6, 0.9)
R10	(0.1, 0.4, 0.4, 0.6)	(0.7, 0.83, 0.87, 1)	(0.1, 0.4, 0.4, 0.6)	(0.4, 0.6, 0.6, 0.9)	(0.7, 0.8, 0.8, 0.9)
R11	(0.4, 0.6, 0.6, 0.9)	(0, 0.23, 0.27, 0.6)	(0.4, 0.7, 0.7, 0.9)	(0.4, 0.7, 0.7, 0.9)	(0.4, 0.63, 0.67, 0.9)
R12	(0.4, 0.73, 0.77, 1)	(0.4, 0.7, 0.7, 0.9)	(0.4, 0.6, 0.6, 0.9)	(0.4, 0.5, 0.5, 0.6)	(0.4, 0.7, 0.7, 0.9)

Table 4. The best and the worst values of the criteria.

f^*	0.72	0.85	0.67	0.80	0.87
f^-	0.15	0.28	0.15	0.50	0.00

Table 5. S_i, R_i, and Q_i values and ranks.

Risks	S_i	**Rank**	R_i	**Rank**	Q_i	**Rank**
R1	1.131	9	0.395	5	0.378	7
R2	0.950	3	0.395	5	0.269	5
R3	0.955	4	0.338	3	0.184	3
R4	0.917	2	0.469	7	0.363	6
R5	1.021	7	0.308	2	0.177	2
R6	1.569	12	0.626	9	1.000	12
R7	1.250	10	0.626	9	0.807	10
R8	0.742	1	0.303	1	0.000	1
R9	1.110	8	0.626	9	0.722	9
R10	0.970	5	0.348	4	0.208	4
R11	0.979	6	0.500	8	0.448	8
R12	1.318	11	0.626	9	0.848	11

It can be seen that both the acceptable advantage and acceptable stability conditions are satisfied in the decision because R8 is ranked 1 among S_i, R_i, and Q_i. Moreover, the following equation is satisfied:

$$Q_2 - Q_1 = 0.177 - 0 = 0.177,\ \frac{1}{n-1} = \frac{1}{11} = 0.09,\ 0.177 \geq 0.09$$

5. Conclusions

In recent years, companies have adopted new technologies that can offer different benefits to the supply chain, but they also have the potential to introduce some risks to different supply chain functions. One of the most important supply chain functions is sustainability, which is an essential part of supply chain worldwide, and there is a strong relationship between sustainability and supply chain performance. Thus, it is vitally important to determine and evaluate the risks that can be caused by digital technologies in sustainability. The aim is to evaluate these risks by utilizing a fuzzy VIKOR method, which is a multi-criteria decision-making method under uncertainty. The VIKOR method aims to identify compromise solutions for problems that have conflicting criteria and to facilitate the decision-making process by arriving at a conclusive decision. In addition, fuzzy sets theory can solve the vagueness of human thinking in an uncertain environment. Therefore, the fuzzy VIKOR method is considered in this paper to evaluate risk factors. According to the results, R8 (risk of lack of IT skills) is the most important risk among all other risk factors, which can exert a pernicious influence on indicators of sustainability performance. As a result, risk mitigation plans should be considered that place greater emphasis on this risk factor. Considering the limitations of this research, only five criteria were used for decision making, but these can be expanded for future studies. Moreover, other decision-making methods, such as fuzzy TOPSIS, fuzzy AHP, fuzzy ELECTRE, can be utilized to evaluate risk factors, and the results can be compared with the findings of this study.

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