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Social Sustainability Risk Assessment of Fresh Produce Supply Chain in China under Computer Technology and Digital Transformation

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Abstract: **-** This paper investigates the social sustainability risks in China's fresh produce supply chain amid ongoing digital transformation. As computer technologies reshape supply chain operations, understanding and mitigating associated social risks become paramount. This research aims to provide a comprehensive assessment of these risks, examining factors such as data and cyber security, inequality, and ethical sourcing concerns. Ten social risk criteria are identified through literature review and expert opinion. In a Sichuan case study, by integrating hybrid methodology Fuzzy Failure Modes and Effects Analysis (FMEA) and Fuzzy VIKOR (VlseKriterijumska Optimizacija I Kompromisno Resenje), Data Privacy and Security Risks (SR1) stands out as the most critical risk criterion in the supply chain with the highest Q value, followed by Ethical Use of Technology (SR4) and Digital Dependency (SR5). This paper offers insights into how stakeholders can navigate the intersection of digitalization and social sustainability to foster more resilient and equitable fresh produce supply chains.

Keywords: Digital Transformation, Fresh Produce Supply Chain, Risk Management, Sustainability, Computer Technology.

I. Introduction

It is projected that the global population will expand to 9 billion by the year 2050, placing significant pressure on the worldwide supply chain for fresh produce [1]. The supply, safety, and quality issues of fresh agricultural products have been a focus of global attention [2]. What strategies can be implemented to foster the sustainable growth of the fresh agricultural product supply chain has always been a core issue of concern for stakeholders [3]. In the contemporary global landscape, the fresh produce supply chain stands as a critical component of the food industry, serving as a conduit for delivering nutritious and essential food items to consumers worldwide. In the past decade, global fresh agricultural product output has increased by 38%, while food safety issues related to fresh agricultural products have been repeatedly observed [4].

Nowadays, fresh agricultural product supply chain faces dual opportunities and challenges of digital transformation and sustainable development. Realizing the complete benefits of digital agriculture requires a collaborative approach spanning diverse fields, which involves devising and rigorously testing multifaceted strategies informed by invaluable insights from behavioral science, agriculture knowledge, economic principles, and data science [5]. Sharma et al. believe that the utilization of data analytics is pivotal in safeguarding future food security, promoting food safety, and fostering ecological sustainability [6]. China is the largest agricultural producer in Asia. The progress of the fresh produce sector holds immense importance for China's economic growth, contributing 5.05% to the GDP in 2022. Over the past years, there has been a consistent upward trajectory in the annual production of fresh produce in China. The fresh produce industry in China has gained substantial momentum, surpassing a yearly output of 1,348,750.6 ten thousand tons in 2022, reflecting a year-on-year growth rate of 2.59% since 2010. There has long been a contradiction between small farmers and large markets in the fresh produce sector in China.

In recent years, the current spotlight on sustainability and its associated concerns is garnering heightened interest among stakeholders [7]. Within the realm of sustainable management, companies are increasingly recognizing their responsibilities towards addressing social and environmental issues. As businesses strive for enduring competitive edges, they find themselves compelled to integrate evaluations of social and environmental risks alongside conventional economic evaluations [8]. The societal aspect of sustainability within supply chains

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has garnered increased attention from both academia and industry. One perspective to consider is that neglecting social factors could potentially harm the overall brand reputation of a company. For instance, several renowned fashion brands such as Levi Strauss, Benetton, and Nike faced significant criticism due to environmental and social issues linked to their suppliers [9]. Sustainability comprises economic, social, and environmental facets, adding layers of complexity to the concept [10]. Nevertheless, organizations are increasingly recognizing the environmental and social repercussions of their operations and are striving to embrace sustainable practices. This shift in strategy is primarily driven by pressure from stakeholders, including consumers, employees, environmental organizations, local communities, non-governmental organizations (NGOs), and regulatory bodies [10]. In today's world of social media dominance, negative experiences related to supply chain disruptions can be rapidly shared with a vast audience, exacerbating the damage to the company's reputation [11]. Traditional supply chain management has long been focused on industrial and service industries, with limited attention paid to fresh agricultural products. The significance of fresh agricultural products in social and environmental realms is frequently underestimated [12]. Incorporating sustainability considerations into perishable food supply chain management has become increasingly vital. Numerous manufacturers produce reports on social and environmental sustainability to meet stakeholder expectations. Supply chain social sustainability addresses various social concerns spanning the entire supply chain process [9].

The utilization of artificial intelligence techniques is imperative for making precise predictions regarding the probability and potential impact of risks [13]. Transformative technologies such as big data analytics, machine learning, blockchain, and cloud computing offer viable solutions to address various challenges, including enhancing productivity and yields, preserving water resources, safeguarding soil and plant vitality, and promoting environmental guardianship [6]. Chod et al. highlight a significant advantage of blockchain adoption: by providing transparency an enterprise's supply chain, blockchain facilitates the attainment of favorable financing terms while minimizing signalizing expenses [14]. Deiva et al. underscore the crucial impact of Twitter in promptly identifying risks in real-time across online supply chain platforms [15]. Machine learning provided an opportunity to mitigate supply chain risks by diminishing dependence on human labor, enhancing response times, and forecasting potential risks [16]. By leveraging Artificial Intelligence and Big Data Analytics, Shah et al. construct a risk profile that empowers decision-makers and risk managers to make timely and informed decisions, thereby mitigating risks in the supply chain and enhancing its resilience [17].

Corbett highlights the inseparable relationship between sustainable development and big data [18]. Enterprises can utilize information technology to dynamically adjust pricing, making products more accessible to new customers [19]. Siddh et al. argue that integrated information management and sustainable development are imperative in future supply chain research [20]. O'Rourke suggest that improved data, decision-making tools, and incentive mechanisms will steer supply chains from a focus on local economic benefits towards a broader emphasis on overall sustainability [21].In recent years, with the advancement of industrial digitization, digital technologies characterized by digitization, networking, and intelligence, such as artificial intelligence, the Internet of Things, the Internet, big data, blockchain, and cloud computing, have become increasingly prevalent in supply chain management [22-24]. Sanders and Ganeshan think that the supply chain is progressing towards becoming a digital network interlinked through various sensors and devices [25].

The agricultural product supply chain has seen extensive integration of digital tools. Meta-analyses reveal that leveraging digital technologies for disseminating agricultural information has led to a 4% boost in yields [5]. The utilization of data analytics is pivotal in securing the future of food, fostering ecological sustainability, and promoting food safety [6]. Saurabh and Dey explore the application framework of blockchain in sustainable supply chains for agricultural products [26]. Miguéis et al. investigated the use of machine learning models to avoid food waste and promote supply chain sustainability and customer satisfaction [27]. Enhancing traceability throughout food supply chains is essential for continuously addressing contamination risks and minimizing food wastage [28]. In 2022, China's digital economy surged to staggering 50.2 trillion CNY, accounting for 41.5% share of the country's GDP. However, the penetration rate of digital economy in agriculture is still less than 10%, which is relatively low compared to developed countries. As China undergoes digital transformation across various industries, including agriculture and food supply chains, the fresh produce sector faces a multitude of challenges and opportunities. From labor conditions and community welfare to consumer rights and ethical sourcing practices, the fresh produce supply chain social aspect is undergoing profound changes, driven by technological innovation and shifting consumer preferences. As digital technologies continue to permeate every aspect of agricultural production, distribution, and consumption, it is imperative to understand the evolving landscape of social risks that accompany this transformation. Amidst this transformation, it becomes imperative to evaluate and address social risks to ensure the long-term sustainability and resilience of the supply chain.

The paper is structured as follows: Section 2 presents an analysis of literature review in the fresh produce supply chain and supply chain risk management under digital era and social sustainability. In Section 3, we outline the criteria used to assess social sustainability risks in the supply chain under digital era. Section 4 introduces a hybrid methodology for evaluating social sustainability risks within this context. Section 5 presents a case study to illustrate the application of this methodology in a real-world setting. Finally, Section 6 concludes the paper by summarizing the key findings and implications.

II. Literature Review

In the context of digitalization, understanding and mitigating social risks associated with fresh agricultural products have become increasingly important. This literature review aims to explore existing research on social risks in the fresh agricultural product sector within the digital era. The literature related to this section covers three main aspects, which will be reviewed and summarized individually.

A. Corporate Social Responsibility (CSR) of Fresh Produce Supply Chain

In recent years, corporate social responsibility has garnered widespread research interest in the business community [29, 30]. Research focusing on the sustainable evolution of supply chains and the principles of corporate social responsibility have surfaced not only within the domain of supply chain management but also within the discourse of business ethics publications [31]. With a growing number of corporations adopting sustainability and corporate social responsibility initiatives, there is mounting pressure to incorporate social impacts across supply chains [10]. However, Traditional supply chain management has long been limited to the industrial and service sectors, with relatively less attention paid to the fresh agricultural products industry. Therefore, the societal and ecological significance of fresh agricultural goods frequently goes unnoticed [12,32]. In the fresh agricultural products industry, corporate social responsibility encompasses food safety, quality, environmental and social sustainability [15]. Rimmington et al. study sustainable food procurement policies in the UK public sector [33]. Maloni and Brown discuss the implementation of corporate social responsibility within the food supply chain, proposing that such responsibility encompasses considerations such as biotechnology, animal welfare, fair trade practices, labor conditions, health and safety standards, human rights, and environmental impact [3]. Manning analyze the interplay between corporate social responsibility and consumer engagement in ethical practices within the food supply chain, employing theoretical modeling methodologies [34]. Liu et al. believe that corporate social responsibility has been regarded as a guarantee for the sustainable development of the supply chain [35]. At the same time, the fresh produce supply chain has positive social impacts by providing ample employment opportunities and promoting economic development [20]. In recent years, companies have increasingly aimed to mitigate unethical practices and reputational risks within their supply chains while embracing their associated social obligations [36]. Corporate social responsibility has emerged as a strategic asset for businesses to demonstrate their good behavior, with European food companies disclosing information through sustainable development reports.

The above-mentioned study considered the corporate social responsibility aspect of the supply chain, but did not integrate digitalization for analysis.

B. Supply Chain Risk Management under Digital Era

Given their dynamic and intricate characteristics, supply chains are susceptible to a multitude of risks [37]. Amidst the landscape of Industry 4.0, supply chains face a multitude of risks stemming from accelerated globalization and the digitization of processes. These risks encompass uncertainties, unforeseen occurrences, and disruptions both within the supply chain network and in the broader global environment [38]. Kusi-Sarpong et al. introduce a holistic framework aimed at identifying and managing the risks associated with the integration of big data analytics in sustainable supply chains [39]. Zheng et al. examine the risk decision-making challenges encountered by stakeholders in a spacecraft supply chain, with a focus on the integration of blockchain technology to enhance information sharing [40]. Liu et al. identify risk elements within the smart supply chain and develop an index system for assessing these risks, aimed at averting potential losses in the domain of intelligent manufacturing [41]. The integration of big data analytics and blockchain technology holds significant promise in efficiently addressing these supply chain risks [37].

Considering the ramifications of incomplete and asymmetrical information on supply chain operational efficiency, Fu and Zhu focus on large-scale production enterprises and explores the utilization of blockchain technology to mitigate endogenous risks within their supply chains, with the aim to investigate the operational mechanisms and practical value of implementing blockchain in this context [42]. Dai and Liu conduct a comprehensive examination of the supply chain risks faced by large retail enterprises in China's agricultural supermarket sector, particularly under the framework of agricultural supermarket docking [43]. Narwane et al. introduce an innovative approach to leveraging big data analytics-blockchain technology to mitigate risks within supply chains [37]. Gupta et al. propose that the combination of big data analytics and additive manufacturing can strengthen risk management strategies and enhance the resilience of a company's supply chain, thereby reducing the escalation of disruptions within the supply chain [44]. The recent progress in technology, exemplified by blockchain technology, has encouraged forward-looking retailers to advocate for the implementation of food traceability systems throughout their supply chains [28]. Shah et al. aspire to undertake an in-depth examination of existing literature concerning the integration of Artificial Intelligence and Big Data Analytics within the domain of Supply Chain Risk Management [17]. Pandey et al. underscore the significance of prioritizing risks such as disruption, cybersecurity, and safety risks within the dynamic landscape of Industry 4.0 [38].

These studies mainly focus on the application of digitalization in other industries, with relatively fewer considerations for its application in agriculture. Furthermore, they also did not take into account research on sustainable social risks. The literature reviewed in this section underscores the need for a more comprehensive understanding of digitalization's impact across different industries, including agriculture, and its implications for sustainable social development. Subsequent studies should endeavor to close these disparities through exploring the intersection of digitalization, agriculture, and social sustainability to inform more holistic and inclusive approaches to digital transformation.

C. Sustainable Social Risk Management of Supply Chain

Efficiently managing risks within a company's supply chain has become instrumental in determining its success and establishing a competitive edge. Although the literature extensively addresses financial risks, there has been relatively limited research on social risks that can impact a company's supply chain [45]. Cunha, et al. explore social risks within supply chains and present a structured framework, taxonomy, and research agenda to navigate future explorations in this area [45]. Rajesh reveals the driving forces behind the management of social and environmental risk management (SERM) within resilient supply chains, emphasizing their pivotal role in encouraging enterprises to adopt SERM practices [8]. Galuchi et al. investigate the primary origins of reputational risks in the beef supply chains of the Brazilian Amazon, along with the strategies implemented by slaughterhouses to address such risks [46].

These studies have examined social risks in supply chains, but there is limited research that integrates fresh agricultural products and digitalization. This study collectively contributes to our understanding of how digitalization influences CSR practices in the fresh agricultural product industry, providing valuable perspectives for industry experts, researchers, and policymakers. The fresh produce supply chain serves as a cornerstone in ensuring widespread access to nutritious food for consumers across the globe. However, in the era of digital transformation, this industry faces a myriad of social risks that can impact its sustainability and resilience. As digital technologies revolutionize the way we produce, distribute, and consume fresh agricultural products, it is imperative to evaluate and address the social risks entailed by these transformations.

III. Risk Identification

Assessing social risks in the fresh produce supply chain under digital transformation involves considering various factors that can impact stakeholders, communities, and society at large. Utilizing the approach outlined by Cunha et al. [45] and Narwane et al. [37], we identified 10 social sustainability risks with digital transformation, including Data Privacy and Security Risks, Digital Divide, Labor Displacement, Ethical Use of Technology, Digital Dependency, Supply Chain Transparency, Regulatory Compliance, Worker Rights, Inequality in Value Distribution and Ethical Sourcing Concerns. The potential social sustainability risks as following:

(1) Data privacy and security risks (SR1): Risks associated with the collection, storage, and transmission of sensitive personal data within the digital supply chain, including the potential for data breaches, identity theft, and unauthorized access. The collection and processing of personal data through digital systems and technologies raise concerns about data privacy and security for workers, vendors, and other stakeholders engaged in the supply network.

(2) Digital divide (SR2): Unequal access to digital tools and technologies among workers, farmers, and communities can exacerbate existing social inequalities. Those lacking access to digital literacy and infrastructure may face barriers to participation in the digital supply chain, limiting their economic opportunities.

(3) Labor displacement (SR3): The implementation of digital technologies such as automation and robotics may lead to job displacement for workers involved in manual tasks like harvesting and packing in the fresh produce supply chain, potentially impacting local economies and communities that rely on agricultural employment.

(4) Ethical use of technology (SR4): Risks associated with the ethical implications of digital technologies, including concerns about algorithmic bias, surveillance, discrimination, and the misuse of data for unethical purposes.

(5) Digital dependency (SR5): Overreliance on digital technologies within the supply chain may create dependencies that leave stakeholders vulnerable to disruptions caused by technological failures, system outages, or cyber incidents, potentially leading to economic losses and social unrest.

(6) Supply chain transparency (SR6): Supply Chain Transparency: While digital technologies can enhance supply chain transparency, there may be risks associated with the misuse or manipulation of data, as well as challenges in verifying the accuracy and authenticity of information shared through digital platforms, particularly in cases of counterfeit goods or fraudulent activities.

(7) Regulatory compliance (SR7): Risks arising from non-compliance with regulations and standards governing digital practices within the supply chain, comprising regulations on data protection, sector-specific standards, and cybersecurity protocols.

(8) Worker rights (SR8): Digital platforms used in the supply chain, such as online marketplaces or labor management systems, may raise concerns about worker rights, encompassing working hours, fair wages, and the availability of benefits and protections. Surveillance technologies and algorithms used to track worker productivity and performance could lead to exploitation, violations of privacy, and erosion of labor rights, if not properly regulated, which can impact job satisfaction, mental health, and work-life balance.

(9) Inequality in value distribution (SR9): Digital platforms and e-commerce channels may alter the value distributed across the supply chain, potentially concentrating profits among large corporations and platforms while marginalizing smaller farmers and suppliers, exacerbating income inequality.

(10) Ethical sourcing concerns (SR10): Employing digital solutions for supply chain optimization and traceability may raise concerns about ethical sourcing practices, including the risk of sourcing from suppliers with poor labor practices, human rights violations, or environmental harm.

Addressing these social risks requires a holistic approach that considers the impacts of digitalization on workers, communities, and broader societal dynamics. This involves promoting inclusive digitalization strategies, safeguarding labor rights and privacy, fostering equitable access to digital technologies, and promoting responsible and ethical business practices throughout the fresh produce supply chain.

IV. Proposed Methodology

In this paper, we utilize the Fuzzy FMEA Fuzzy Failure Mode and Effect Analysis (Fuzzy Failure Mode and Effect Analysis) and Fuzzy VIKOR (VlseKriterijumska Optimizacija I Kompromisno Resenje) methodology pioneered by Wu et al. and Liu et al. [47, 48]. Fuzzy FMEA extends the traditional FMEA method by integrating fuzzy logic, which effectively addresses uncertainties and vagueness inherent in risk assessment. Our approach considers occurrence (O), severity (S), and detection (D) as key risk factors, with their respective importance weights represented as linguistic variables. In order to precisely account for the subjective evaluations made by decision-makers, we employ linear trapezoidal membership functions, which are well-suited for handling the inherent vagueness in linguistic evaluations. We introduce a systematic methodology for applying the fuzzy VIKOR method to prioritize risk criteria within a fuzzy environment. In our investigation, we regard the significance weights allocated to risk factors and the fuzzy assessments of failure modes for each risk factor as linguistic variables. To ensure clarity, we represent these linguistic variables using positive trapezoidal fuzzy numbers, as detailed in Tables 1 and 2 [47].

Table 1: Linguistics Variable Values of Risk Criteria

Linguistics variables	Fuzzy numbers
Very low (VL)	(0,0,1,2)
Low (L)	(1,2,2,3)
Medium Low (ML)	(2,3,4,5)
Medium (M)	(4,5,5,6)
Medium high (MH)	(5,6,7,8)
High (H)	(7,8,8,9)
Very high (VH)	(8,9,10,10)

Table 2: Linguistics Variable for Rating the Weights of Risk Factors

Linguistics variables	Fuzzy numbers
Very low (VL)	(0,0,0.1,0.2)
Low (L)	(0.1,0.2,0.2,0.3)
Medium Low (ML)	(0.2,0.3,0.4,0.5)
Medium (M)	(0.4,0.5,0.5,0.6)
Medium high (MH)	(0.5,0.6,0.7,0.8)
High (H)	(0.7,0.8,0.8,0.9)
Very high (VH)	(0.8,0.9,1.0,1.0)

The details of hybrid fuzzy FMEA-FVIKOR method refer to references Wu et al. and Liu et al. [47, 48].

V. Case Study

Over the past few years, the fresh produce supply chain in China has experienced notable digital evolution, driven by advancements in technology and changing consumer preferences. This case study explores the social risk assessment within the context of this digital transformation, focusing on a prominent fresh produce distributor in China. The company, referred to as A, operates a nationwide network of distribution centers and retail outlets, focusing on the sourcing and delivery of fresh agricultural products. With the rise of e-commerce and digital platforms, Company A has embraced digital transformation initiatives to optimize its supply chain operations and enhance customer experience.

Company A has implemented several digital technologies to optimize its supply chain operations and enhance operational effectiveness. These include the adoption of blockchain for traceability and transparency, IoT devices for real-time monitoring of inventory and logistics, and AI-powered analytics for demand forecasting and inventory management. Despite the benefits of digital transformation, A has identified several social risks associated with its supply chain operations.

Company A has chosen to implement an assessment system designed to thoroughly examine the social risks throughout the entirety of its supply chain under digital environment. To support this endeavor, a dedicated task force has been formed, consisting of five professionals. The team consists of a supplier representative, a customer relations specialist, a senior executive, a social consultant, and a supply chain manager. Each member contributes valuable insights and expertise within their field to enhance the decision-making process.

The company utilizes advanced methodologies such as Fuzzy FMEA-VIKOR to conduct a thorough assessment of social risks within the supply chain. After conducting extensive research and carefully reviewing the current situation, the five decision-makers reached a unanimous agreement. They unanimously endorsed ten social risks criteria with digital transformation. They are Data Privacy and Security Risks (SR1), Digital Divide (SR2), Labor Displacement (SR3), Ethical Use of Technology (SR4), Digital Dependency (SR5), Supply Chain Transparency (SR6), Regulatory Compliance (SR7), Worker Rights (SR8), Inequality in Value Distribution (SR9) and Ethical Sourcing Concerns (SR10).

A. *The Process of Assessment*

The process for evaluating social risk under digital environment can be summarized as follows:

Step 1: After conducting thorough research and consulting with experts, social risk criteria related to digital transformation across the entirety of the supply chain have been delineated.

Step 2: A team consisting of five decision-makers, referred to as D1, D2, D3, D4, and D5, has been formed to evaluate the most significant risks. Risk factors denoted as O, S, and D have been identified based on historical data and responses from a questionnaire completed by all decision-makers.

Step 3: The team of five decision-makers utilizes linguistic weighting variables, detailed in Table 2, to determine the relative importance of the risk factors. The significance weights assigned to these risk factors by the decision-makers are summarized in Table 3. Furthermore, employing linguistic rating variables depicted in Table 1, the decision-makers assess the ratings of failure modes associated with each risk factor. The evaluations provided by the decision-makers for the ten risk criteria across the three risk factors are provided in Table 4.

Table 3: Assessment of Risk Factor Importance by the Five Decision-makers

	D1	D2	D3	D4	D5
O	MH	H	VH	VH	M
S	H	VH	MH	H	MH
D	M	H	H	VH	ML

Table 4: Decision-makers' Evaluations of Risk Criteria Considering the Risk Factors

	D1			D2			D3			D4			D5		
	O	S	D	O	S	D	O	S	D	O	S	D	O	S	D
SR1	H	MH	M	MH	VH	H	M	ML	H	H	VH	MH	ML	VH	MH
SR2	VH	ML	ML	M	H	M	MH	MH	ML	H	H	MH	MH	M	L
SR3	H	M	ML	M	MH	ML	MH	M	L	H	H	ML	H	ML	VL
SR4	M	H	MH	ML	H	MH	ML	H	MH	MH	H	M	ML	H	H
SR5	M	MH	L	H	VH	H	MH	VH	M	ML	VH	H	MH	MH	MH
SR6	MH	H	L	L	MH	MH	L	MH	ML	MH	VH	MH	L	H	M
SR7	ML	L	M	ML	H	VL	ML	H	L	M	VH	H	VL	VH	VL
SR8	MH	M	ML	MH	H	L	M	MH	ML	MH	M	ML	ML	MH	L
SR9	L	M	H	M	MH	ML	MH	M	M	M	ML	L	L	MH	ML
SR10	M	H	ML	MH	VH	MH	L	VH	L	M	MH	MH	ML	VH	M

Step 4: The linguistic evaluations provided in Tables 3 and 4 are transformed into trapezoidal fuzzy numbers. Subsequently, the cumulative weight of risk factors and the aggregated fuzzy ratings of risks are computed to establish the fuzzy weight assigned to each risk factor and to construct the fuzzy decision matrix, as shown in Table 5.

Table 5: Aggregated Fuzzy Ratings of Risk Criteria and Aggregated Fuzzy Weight of Risk Factors

	O	S	D
SR1	(2.0, 6.0,6.4,9.0)	(5.0,8.4, 9.4,10.0)	(2.0,5.6,6.2,9.0)
SR2	(4.0,6.8,7.4,10.0)	(2.0,6.0,6.4,9.0)	(1.0,3.8,4.4,8.0)
SR3	(4.0,7.0,7.2,9.0)	(2.0,5.4,5.8,9.0)	(0.0,2.2,3.0,5.0)
SR4	(2.0,4.0,4.8,8.0)	(7.0,8.0,8.0,9.0)	(4.0,6.2,6.8,9.0)
SR5	(2.0,5.6,6.2,9.0)	(5.0,7.8,8.8,10.0)	(1.0,5.8,6.0,9.0)
SR6	(1.0,3.6,4.0,8.0)	(5.0,7.4,8.0,10.0)	(1.0,3.8,4.4, 8.0)
SR7	(0.0,2.8,3.6,6.0)	(1.0,7.2,7.6,10.0)	(0.0,3.0,3.4,9.0)
SR8	(2.0,5.2,6.0,8.0)	(4.0,6.0,6.4,9.0)	(1.0, 2.6,3.2,5.0)
SR9	(1.0,4.0,4.2,8.0)	(2.0,5.0,5.6,8.0)	(1.0,4.2,4.6,9.0)
SR10	(1.0,4.2,4.6,8.0)	(5.0, 8.2,9.0,10.0)	(1.0,4.4,5.0,8.0)
Weight	(0.40,0.74,0.80,1.00)	(0.50,0.74,0.80,1.00)	(0.20,0.66,0.70,1.00)

Step 5: The crisp values for the decision matrix and the weight assigned to each risk factor are determined, as demonstrated in Table 6.

Table 6: Crisp Values for Decision Matrix and Weight for Each Risk Factor

	O	S	D
SR1	5.7459	8.0444	5.6439
SR2	7.0364	5.7459	4.3561
SR3	6.7077	5.5351	2.5379
SR4	4.7765	8.0000	6.5000
SR5	5.6439	7.8111	5.3073
SR6	4.2541	7.5738	4.3561
SR7	3.0745	6.1603	4.0482
SR8	5.2235	6.3926	2.9623
SR9	4.3630	5.1091	4.7905
SR10	4.4649	7.9172	4.5719
Weight	0.7255	0.7574	0.6279

Step 6: The best and worst values for all risk factor ratings are identified through the following process:

$$f_O^* = 3.0745,\ f_S^* = 5.1091,\ f_D^* = 2.5379 \quad (1)$$

$$f_O^- = 7.0364,\ f_S^- = 8.0444,\ f_D^- = 6.5000 \quad (2)$$

Step 7: The values S, R, and Q are computed for all risk criteria, as presented in Table 7.

Table 7: The Values of S, R and Q for All Risk Criteria

	SR1	SR2	SR3	SR4	SR5	SR6	SR7	SR8	SR9	SR10
S	1.7388	1.1779	0.7752	1.6855	1.6066	1.1401	0.5106	0.7919	0.5929	1.3015
R	0.7574	0.7255	0.6653	0.7459	0.6972	0.6359	0.2712	0.3935	0.3570	0.7246
Q	1.0000	0.7388	0.5130	0.9665	0.8842	0.6314	0.0000	0.2403	0.1217	0.7882

Step 8: The risk criteria are ranked based on their S, R, and Q values in descending order, as depicted in Table 8.

$$Q(A^{(2)}) - Q(A^{(1)}) = 0.1217 \geq \frac{1}{10-1} = 0.1111 \quad (3)$$

Cond1 was satisfied and SR1 was also the best ranked criteria. Since both Cond1 and Cond2 were verified, SR1 was the key focus risk indicator.

Table 8: The Ranking of the Risk Criteria by S, R and Q

	SR1	SR2	SR3	SR4	SR5	SR6	SR7	SR8	SR9	SR10
By S	1	5	8	2	3	6	10	7	9	4
By R	1	3	5	2	6	10	9	7	8	4
By Q	1	5	7	2	3	6	10	8	9	4

B. Results and Discussion

As indicated in Table 8, the prioritization of risk criteria according to Q values in descending order are Data Privacy and Security Risks (SR1)> Ethical Use of Technology (SR4)> Digital Dependency (SR5)> Ethical Sourcing Concerns (SR10)> Digital Divide (SR2)> Supply Chain Transparency (SR6)>Labor Displacement (SR3)> Worker Rights (SR8)> Inequality in Value Distribution (SR9)> Regulatory Compliance (SR7).

The most critical risk criteria: It is evident that Data Privacy and Security Risks (SR1) stands out as the most critical risk criteria based on Q values, warranting top priority in terms of risk management by the company. The identification of SR1 as the most critical social risk criterion within the fresh produce sustainable supply chain in China under digital transformation underscores the profound implications of safeguarding sensitive information in the contemporary business environment.

The prioritization of SR1 highlights the paramount importance of addressing data privacy and security concerns in the context of China's fresh produce supply chain. As supply chain operations become increasingly digitized, protecting sensitive data has become indispensable to guarantee the integrity, trust, and resilience of the entire supply chain ecosystem. The fresh produce supply chain, in particular, faces unique challenges in maintaining data privacy and security due to its complex and interconnected nature. From farm to table, multiple stakeholders are involved in the production, distribution, and retailing of fresh produce, creating numerous touchpoints vulnerable to cyber threats and data breaches. Failure to address SR1 could lead to extensive repercussions for the longevity and robustness of the supply chain. Beyond financial losses and operational disruptions, breaches in data privacy and security can erode consumer trust, damage brand reputation, and lead to legal and regulatory repercussions.

Given the critical nature of SR1, stakeholders must implement comprehensive solutions to mitigate data privacy and security risks effectively. This may include investing in advanced cybersecurity technologies, implementing robust data protection policies and protocols, conducting regular risk assessments and audits, and providing ongoing training and awareness programs to employees. Addressing SR1 requires collaborative efforts among government agencies, industry associations, businesses, and technology providers. By sharing best practices, exchanging information, and collaborating on cybersecurity initiatives, stakeholders can collectively strengthen the resilience of Chinese fresh produce supply chain and mitigate the potential impact of data privacy and security risks.

In conclusion, SR1 as the most critical social risk criteria underscores the urgent need for supply chain stakeholders to prioritize data protection and cybersecurity measures in the face of digital transformation. It is crucial to implement proactive risk management strategies and foster collaboration throughout the supply chain to protect sensitive information and uphold the integrity and resilience of the fresh produce supply chain in the digital age.

1) The second critical risk criteria: Following Data Privacy and Security Risks (SR1), in descending order of risk priority, are Ethical Use of Technology (SR4). SR4 as the second critical social risk criterion in the fresh produce sustainable supply chain in China under digital transformation underscores the importance of ethical considerations in the adoption and integration of technology. The swift digital evolution in China poses distinctive challenges concerning the ethical application of technology within the supply chain. As companies embrace advanced technologies like AI, IoT, and blockchain, they must navigate ethical dilemmas concerning data privacy, transparency, and responsible innovation.

SR4 encompasses concerns related to data privacy and security, particularly in the collection, storage, and processing of sensitive information. In China, where data regulations are evolving, companies face scrutiny over data handling practices and must ensure compliance with emerging privacy laws to protect consumer rights and mitigate the risk of data breaches. Ethical technology use requires transparency and accountability throughout the supply chain. Chinese companies must uphold transparency standards in algorithmic decision-making, supply chain traceability, and product labeling to maintain consumer trust and confidence in the integrity of their operations.

The ethical implications of technology extend to labor rights and workforce automation. As China's manufacturing sector undergoes automation and digitalization, companies must address concerns related to job displacement, worker safety, and fair treatment to uphold ethical labor practices and social responsibility. SR4 also encompasses environmental ethics considerations, such as the ecological impact of technology use and sustainable resource management. Chinese enterprises are facing mounting pressure to embrace environmentally friendly technologies, curtail carbon emissions, and mitigate environmental impact throughout the supply chain to fulfill sustainability objectives and comply with regulatory mandates.

Ethical technology use in China's supply chain is subject to government oversight and regulation. Companies must navigate regulatory complexities and ensure compliance with laws governing data protection, cybersecurity, and ethical business practices to avoid legal repercussions and reputational damage. Addressing SR4 requires cooperation and involvement with various stakeholders, such as governmental bodies, industry groups, civil society organizations, and community members. Through involving stakeholders in decision-making processes and promoting transparency and dialogue, companies can build trust and credibility while mitigating social and ethical risks.

In conclusion, Ethical Use of Technology (SR4) represents a critical social risk criterion in China's fresh produce sustainable supply chain under digital transformation. By prioritizing ethical considerations, companies can enhance trust, promote transparency, ensure compliance, and foster sustainable innovation, ultimately aiding in the sustained strength and viability of the supply chain ecosystem in China.

2) The third critical risk criteria: The identification of Digital Dependency (SR5) as a critical social risk criterion within China's fresh produce sustainable supply chain under digital transformation underscores the significant impact of technological reliance on supply chain resilience. SR5 highlights the heavy reliance on digital technologies within China's fresh produce supply chain. As businesses increasingly adopt digital solutions for various supply chain activities such as procurement, inventory management, and distribution, they become more vulnerable to disruptions arising from technological failures, cyberattacks, or infrastructure breakdowns.

The reliance on digital systems exposes the supply chain to various vulnerabilities, including software glitches, network outages, and cybersecurity threats. Any disruption in digital infrastructure can disrupt operations, leading to delays in product delivery, inventory shortages, and financial losses for businesses engaged in the supply chain.

Relying heavily on digital technology presents considerable hurdles to supply chain resilience, as disruptions in digital systems can reverberate throughout the entire supply chain network. The failure to swiftly rebound from digital disruptions can jeopardize the agility and adaptability of the supply chain, rendering it more vulnerable to external shocks and disturbances.

To address SR5 effectively, stakeholders in China's fresh produce supply chain must implement robust mitigation strategies. This may include diversifying digital infrastructure to reduce dependency on single systems or providers, implementing backup and redundancy measures, enhancing cybersecurity measures, and investing in technologies that enhance resilience, such as blockchain and IoT. Addressing Digital Dependency requires collaboration among stakeholders across the supply chain. By sharing best practices, exchanging information, and collaborating on technological initiatives, stakeholders can collectively bolster the resilience of the supply chain and alleviate the effects of digital disruptions.

In conclusion, Digital Dependency (SR5) represents a critical social risk criterion that underscores the challenges associated with technological reliance in China's fresh produce supply chain under digital transformation. Proactive measures, collaborative efforts, and investments in resilient technologies are essential to mitigate the risks posed by digital dependencies and guarantee the enduring viability of the supply chain ecosystem.

3) Other risk criteria: Ethical Sourcing Concerns (SR10) the fourth important risk. Given China's diverse agricultural landscape and the complexities of its supply chains, ethical sourcing concerns are likely critical. This includes issues related to labor practices, environmental sustainability, and fair trade, particularly as digital transformation reshapes sourcing and procurement processes.

Digital Divide (SR2) is the fifth critical risk criteria. In the context of China's digital transformation, addressing the digital divide is crucial to ensure equitable access to technology and digital resources across various regions and stakeholders in the fresh produce supply chain. It may involve initiatives to bridge gaps in digital literacy, infrastructure, and access to digital tools and information.

Supply Chain Transparency (SR6) is the sixth important risk criteria. Supply chain transparency is vital for building trust and accountability in fresh produce supply chains, especially amidst digital transformation efforts. This involves providing stakeholders with visibility into the origin, journey, and conditions of products, facilitated by technological advancements like blockchain and IoT.

Labor Displacement (SR3) is the seven critical risk criteria. As automation and digital technologies become more prevalent in fresh produce supply chains, apprehensions regarding labor displacement may emerge. This has the potential to affect workers across different phases of the supply chain, ranging from farming to distribution, highlighting the need for strategies to mitigate the social impacts of technological advancements.

Worker Rights (SR8) is the eighth important risk criteria. Ensuring the protection of worker rights is essential in the context of China's fresh produce supply chains, where labor conditions and rights may vary across regions and sectors. Digital transformation should not compromise fundamental worker rights, such as equitable remuneration, secure work environments, and the freedom to associate.

Inequality in Value Distribution (SR9) is the ninth important risk criteria. Addressing inequality in value distribution is a pertinent issue in China's fresh produce supply chains, where disparities in economic benefits and opportunities may exist. Digital transformation should aim to create more equitable value-sharing mechanisms that benefit all stakeholders, including farmers, workers, and consumers.

Regulatory Compliance (SR7) is the lowest priority in the ranking. While regulatory compliance is essential, its lower prioritization in this context suggests that the focus may be on addressing broader social risks beyond mere legal requirements. Nonetheless, compliance with relevant regulations, standards, and certifications remains important to ensure ethical and sustainable practices across the entire supply chain.

Ali et al. point that businesses have the potential to enhance their supply chain resilience by implementing the suggested methodology, which involves fostering a culture of risk management, increasing employee awareness of risks, and conducting regular risk assessment drills [49]. In summary, the prioritization of social risk criteria in the context of fresh produce sustainable supply chains under digital transformation in China demonstrates a nuanced comprehension of the complex challenges and potential advantages embedded in this evolving environment. By addressing these prioritized risks, stakeholders can work towards building more resilient, ethical, and sustainable supply chains that benefit both people and the planet.

VI. CONCLUSION

In this study, we utilized a hybrid methodology fuzzy FMEA-VIKOR to assess social sustainability risk priorities of fresh produce supply chain in China under digital era. We developed a thorough risk evaluation framework based on ten criteria, drawing from expert insights and literature analysis.

Through conducting a case study in Sichuan, China, we have demonstrated how our fuzzy FMEA-VIKOR model effectively streamlines criticality analysis, providing a clear and user-friendly approach. According to the resulting scores, Data Privacy and Security Risks (SR1) stands out as the primary risk index in the supply chain, with the highest Q value. Additionally, Ethical Use of Technology (SR4) and Digital Dependency (SR5) are identified as the second and the third important risks criteria based on our risk evaluation model.

In conclusion, the digitization of the fresh produce supply chain in China presents both opportunities and challenges for social risk assessment and management. Throughout this paper, we have explored the intersection of digital transformation and social risk assessment, highlighting the complexities and implications for stakeholders involved in the fresh produce supply chain. Technological innovations like blockchain, IoT, and AI present compelling opportunities for improving transparency, traceability, and operational efficiency in supply chain management. However, they also introduce new risks related to data privacy, cybersecurity, and ethical considerations. Effective risk assessment and management strategies are essential to confront these obstacles and safeguard the sustainability and durability of the supply chain.

By leveraging digital tools and analytics, stakeholders can gain insights into potential social risks and take proactive measures to mitigate them. Stakeholder engagement, supply chain transparency initiatives, and the development of ethical sourcing practices are critical for promoting social responsibility and accountability throughout the supply chain. Moving forward, there is a need for continued research and collaboration to further understand the impact of digital transformation on fresh produce supply chain social risk assessment. Empirical studies examining risk management approaches efficacy in the digital age are essential for guiding policy and practice.

Ultimately, by embracing the opportunities afforded by digital transformation while addressing its associated risks, stakeholders can foster a more sustainable and socially responsible fresh produce supply chain in China. Through collective efforts and collaboration, we can work towards a future where the digital transformation of the supply chain yields advantages for both enterprises and the entire community.

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