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A Robust Neutrosophic Model for Risk Management in Livestock Supply Chains: A Case Study Towards Sustainable Practices

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Abstract
This study proposed a decision machining methodology to identify and evaluate the risks based on the livestock supply chain (LSC). The risks related to LSC are identified and collected by the opinion of the experts and decision-makers. We collected 11 LSC criteria and nine alternatives. We proposed an uncertainty framework to deal with uncertainty and vague information in the evaluation process. We used the type-2 neutrosophic set (T2NSs) to deal with vague data. The T2NSs were proposed under multi-objective optimization based on simple ratio analysis (MOOSRA) to rank the alternatives. We identified nine strategies to reduce risks in LSC. The results show that operational risks have the highest weights. We applied sensitivity analysis to show the different ranks of alternatives under different criteria weights. The results show the proposed method is stable under different weights. Finally, we conducted a comparative analysis between other methods to show the robustness of the proposed method.

Keywords: Neutrosophic Set; Livestock; Supply Chain (SC); Sustainability; Risk Management.

1. Introduction

Disruptions to the supply chain (SC) have affected business performance in recent years. In this field, the Ericsson example is well known. In 2000, a fire at a Phillips semiconductor plant interrupted production, ultimately resulting in a $400 million loss for Ericsson. Toyota's output fell by 40,000 automobiles because of the 2011 earthquake, tsunami, and nuclear disaster that struck Japan, losing the company $72 million every day[1], [2]. The October 2011 devastating floods in Thailand had an impact on the SC of hard drive-dependent computer firms. Much effort is made in the field of supply chain risk management (SCRM) in both academic and practitioner circles to regulate and lessen the adverse impacts brought on by such hazards[3], [4], [5]. The livestock supply chain (LSC) is susceptible to various risks at different stages, from production to consumption. Conducting a risk assessment in this domain requires evaluating specific criteria that reflect these vulnerabilities and identifying potential mitigation strategies[6], [7]. A multi-criteria decision-making (MCDM) problem that considers several criteria and options is thus how risk management is defined in LSC. The MCDM approaches using neutrosophic fuzzy sets have been used to better address uncertainty for a variety of applications[8], [9], [10].

Multi-objective optimization techniques include multi-objective optimization based on simple ratio analysis (MOOSRA) and multi-objective optimization by ratio analysis with the full multiplicative form (MULTIMOORA). While the MOOSRA technique computes the simple ratio of advantageous and non-beneficial criteria during the decision-making process, the MULTIMOORA approach summarizes the MOORA method, including the ratio system, reference point, and the full multiplicative form. Each criterion is given a weight based on the decision maker's assessment of its significance[11], [12].

Among the multi-objective optimization techniques is the MOOSRA approach. When the MOOSRA and MOORA methods are compared, the MOOSRA technique is less sensitive to significant fluctuations in the criterion values and does not exhibit the negative performance scores of the MOORA approach[13], [14], [15]. It was utilized in the creation of a multi-criteria decision-making framework to determine the best cutting parameters for surface roughness, choose the best-cutting fluid from three different types for a gear operation, choose materials, and use non-traditional machinery[16], [17].

The main contribution of this study is organized as follows:

- It is the first time to propose the MOOSRA method under type-2 neutrosophic sets to rank the alternatives in this study.
- We proposed a decision-making model for risk management in LSC to compute the criteria weights and rank the alternatives.
- The type-2 neutrosophic sets are used to deal with vague data.
- This study proposed a set of strategies to overcome the risks in LSC.

The rest of this paper is organized as follows: Section 2 shows the proposed methodology. Section 3 shows the results and discussion. Section 4 shows the sensitivity analysis. Section 5 shows the comparative analysis. Section 6 shows a comparative analysis. Section 7 shows the conclusions.

2. Type-2 Neutrosophic Methodology

This section shows some definitions of T2NSs and the steps of the proposed methodology.

- **Definition 1.**

We can define the T2NSs [18]as:

$P = \{x, A(x), B(x), C(x) | x \in X\}$

Where $A(x) = \left(A_A(X), A_B(X), A_C(X)\right), B(x) = \left(B_A(X), B_B(X), B_C(X)\right), and\ C(x) = \left(C_A(X), C_B(X), C_C(X)\right)$

- **Definition 2** [19], [20], [21]**.**

Let $A_1 = \left(\left(A_{A_1}(X), A_{B_1}(X), A_{C_1}(X)\right), \left(B_{A_1}(X), B_{B_1}(X), B_{C_1}(X)\right), \left(C_{A_1}(X), C_{B_1}(X), C_{C_1}(X)\right)\right)$ and

$A_2 = \left(\left(A_{A_2}(X), A_{B_2}(X), A_{C_2}(X)\right), \left(B_{A_2}(X), B_{B_2}(X), B_{C_2}(X)\right), \left(C_{A_2}(X), C_{B_2}(X), C_{C_2}(X)\right)\right)$ are two T2NNs and operations can be defined as:

$$A_1 \oplus A_2 = \begin{pmatrix} \begin{pmatrix} A_{A_1}(X) + A_{A_2}(X) - A_{A_1}(X)A_{A_2}(X), \\ A_{B_1}(X) + A_{B_2}(X) - A_{B_1}(X)A_{B_1}(X), \\ A_{C_1}(X) + A_{C_2}(X) - A_{C_1}(X)A_{C_2}(X) \end{pmatrix}, \\ \left(B_{A_1}(X)B_{A_2}(X), B_{B_1}(X)B_{B_2}(X), B_{C_1}(X)B_{C_1}(X)\right), \\ \left(C_{A_1}(X)C_{A_2}(X), C_{B_1}(X)C_{B_2}(X), C_{C_1}(X)C_{C_2}(X)\right) \end{pmatrix} \tag{1}$$

$$A_1 \otimes A_2 = \begin{pmatrix} \left(A_{A_1}(X)A_{A_2}(X), A_{B_1}(X)A_{B_2}(X), A_{C_1}(X)A_{C_2}(X)\right), \\ \begin{pmatrix} B_{A_1}(X) + B_{A_2}(X) - B_{A_1}(X)B_{A_2}(X), \\ B_{B_1}(X) + B_{B_2}(X) - B_{B_1}(X)B_{B_2}(X), \\ B_{C_1}(X) + B_{C_2}(X) - B_{C_1}(X)B_{C_2}(X) \end{pmatrix} \\ \begin{pmatrix} C_{A_1}(X) + C_{A_2}(X) - C_{A_1}(X)C_{A_2}(X), \\ C_{B_1}(X) + C_{B_2}(X) - C_{B_1}(X)C_{B_2}(X), \\ C_{C_1}(X) + C_{C_2}(X) - C_{C_1}(X)C_{C_2}(X) \end{pmatrix} \end{pmatrix} \tag{2}$$

$$\rho A_1 = \begin{pmatrix} \left(\left(1-\left(1-A_{A_1}(X)\right)\right)^{\rho}, 1-\left(1-A_{B_1}(X)\right)^{\rho}, 1-\left(1-A_{B_1}(X)\right)^{\rho}\right), \\ \left(\left(B_{A_1}(X)^{\rho}\right), \left(B_{B_1}(X)^{\rho}\right), \left(B_{B_1}(X)^{\rho}\right)\right), \\ \left(\left(C_{A_1}(X)^{\rho}\right), \left(C_{B_1}(X)^{\rho}\right), \left(C_{B_1}(X)^{\rho}\right)\right) \end{pmatrix} \tag{3}$$

$$A_1^{\rho} = \begin{pmatrix} \left(\left(A_{A_1}(X)\right)^{\rho}, \left(A_{B_1}(X)\right)^{\rho}, \left(A_{C_1}(X)\right)^{\rho}\right), \\ \left(1-\left(1-B_{A_1}(X)\right)^{\rho}, 1-\left(1-B_{B_1}(X)\right)^{\rho}, 1-\left(1-B_{C_1}(X)\right)^{\rho}\right), \\ \left(1-\left(1-C_{A_1}(X)\right)^{\rho}, 1-\left(1-C_{B_1}(X)\right)^{\rho}, 1-\left(1-C_{C_1}(X)\right)^{\rho}\right) \end{pmatrix} \tag{4}$$

Definition 3.

The score function can be computed as follows[22]:

$$S(A_1) = \frac{1}{12}\begin{pmatrix} 8 + \left(A_{A_1}(X) + 2A_{B_1}(X) + A_{C_1}(X)\right) \\ -\left(B_{A_1}(X) + 2B_{B_1}(X) + B_{C_1}(X)\right) \\ -\left(C_{A_1}(X) + 2C_{B_1}(X) + C_{C_1}(X)\right) \end{pmatrix} \tag{5}$$

Definition 4.

The accuracy function can be computed as follows:

$$S(A_1) = \frac{1}{4}\begin{pmatrix} \left(\left(A_{A_1}(X)\right) + 2\left(A_{B_1}(X)\right) + \left(A_{C_1}(X)\right)\right) - \\ \left(C_{A_1}(X)\right) + 2\left(C_{B_1}(X)\right) + \left(C_{C_1}(X)\right) \end{pmatrix} \tag{6}$$

3.1 The T2N-MOOSRA Method

We used the T2N- MOOSRA methodology for ranking the strategies to reduce risks in LSC. We used a set of criteria and alternatives in this study. The criteria are presented as $RRY_j(i = 1,2, \ldots, m)$ and the alternatives can be represented as $RRX_i(i = 1,2, \ldots, n)$. The steps of the proposed methodology are presented as:

Step 1. Construct the decision matrix.

The decision matrix is constructed by the opinions of experts.

$$R = \begin{bmatrix} r_{11} & \cdots & r_{1n} \\ \vdots & \ddots & \vdots \\ r_{m1} & \cdots & r_{mn} \end{bmatrix} \quad (7)$$

Step 2. Determine the score function

We obtained the score values in the decision matrix.

Step 3. Combine the decision matrix.

Step 4. The normalization of decision matrix is computed as:

$$h_{ij} = \frac{r_{oj}}{\sqrt{\sum_{i=1}^{m} r_{ij}^2}} \quad (8)$$

Step 5. Compute the criteria weights.

The criteria weights are computed using the average method.

Step 6. Compute the weighted normalized decision matrix.

$$T_{ij} = w_j * h_{ij} \quad (9)$$

Step 7. Compute the score values.

$$S_i = \frac{\sum_{j=1}^{m} U_j(w_j)T_{ij}}{\sum_{j=m+1}^{n} T_j(w_j)T_{ij}} \quad (10)$$

Where U refers to the benefit and cost criteria.

Step 8. Rank the alternatives.

3. Results and Discussion

In this section, we present the outcomes derived from applying the proposed methodology for risk management in the LSC. The analysis is based on 11 key criteria and nine potential alternatives, which were carefully selected to reflect the most significant factors impacting the SC's sustainability and efficiency.

3.1 Criteria for Risk Management

The study identified and classified 11 critical risk categories, each representing a distinct aspect of the LSC that could potentially affect its overall stability. These criteria were chosen based on their relevance and impact on the SC's functionality. Below is a brief explanation of each criterion:

- **Technological Risks**: These risks arise from the potential failure of technology integration or the obsolescence of current systems. The rapid pace of technological advancements means that SC must be continuously updated to avoid vulnerabilities.
- **Policy Risks**: Policy risks refer to the uncertainties related to changes in government regulations or policies. These can significantly affect the operation of SC, especially when new laws or trade agreements are introduced.
- **Regulatory Risks**: Closely related to policy risks, regulatory risks involve compliance with industry standards, environmental laws, and health regulations. Non-compliance could lead to legal penalties or disruptions in operations.

- **Transportation Risks**: This criterion encompasses risks associated with the movement of goods, including disruptions caused by natural disasters, logistical failures, or delays in transportation networks.
- **Infrastructure Risks**: These risks are related to the physical and organizational infrastructure required to operate the SC. Any failure in infrastructure, such as transportation networks, storage facilities, or equipment, could cause severe delays or operational bottlenecks.
- **Market and Demand Risks**: This involves uncertainty around market conditions, consumer demand fluctuations, and market access. Unexpected changes in demand can lead to either surplus or shortage situations, both of which can be costly.
- **Operational Risks**: Operational risks arise from inefficiencies or disruptions within the internal operations of the SC. This includes issues like workforce challenges, equipment malfunctions, or production delays.
- **Environmental Risks**: These risks are linked to natural disasters, climate change, and other environmental factors that could harm livestock or disrupt SC activities. Environmental risks are becoming increasingly important as sustainability and climate adaptation become global priorities.
- **Supply Risks**: Supply risks refer to disruptions in the availability of resources, such as raw materials, feed, or livestock. These risks can be caused by both external factors (e.g., weather conditions) and internal factors (e.g., poor supplier performance).
- **Financial Risks**: Financial risks deal with the economic aspects of the SC, including exchange rate fluctuations, price volatility, and the availability of financial resources to support operations.
- **Social Risks**: Social risks include labor disputes, changes in workforce availability, and community relations. These risks affect the workforce and the community that supports the SC's operations.

3.2 Alternatives for Risk Mitigation

The study also identified nine potential alternatives for managing and mitigating the risks in the LSC. These alternatives were selected based on their ability to address the various criteria effectively:

- **Technology Integration**: This alternative focuses on the adoption of modern technologies, such as automation, data analytics, and blockchain, to streamline operations and reduce technological risks. Integrating technology improves efficiency and enhances transparency in the SC.
- **Market Strategies**: Adapting market strategies involves aligning the SC to meet shifting demand and market conditions. This strategy aims to address market and demand risks by diversifying customer bases and improving market forecasting techniques.
- **Environmental Adaptation**: This alternative emphasizes the need to adjust operations in response to environmental challenges. Implementing sustainable practices and climate-resilient strategies can help manage environmental risks, ensuring that the SC is prepared for changes in weather patterns and environmental regulations.
- **Workforce and Community Engagement**: Fostering strong relationships with the workforce and the surrounding community can reduce social risks. By ensuring fair working conditions and promoting community engagement, organizations can mitigate labor-related disruptions and strengthen public support for the SC.
- **Infrastructure and Logistics**: This alternative focuses on strengthening the physical infrastructure and logistical systems. Investing in more robust storage, transportation, and processing facilities helps minimize infrastructure risks and ensures a smoother flow of goods throughout the SC.

- **Policy Advocacy and Compliance**: Engaging in policy advocacy ensures that the SC is not caught off guard by regulatory changes. By staying involved in policy discussions and complying with relevant regulations, businesses can reduce both policy and regulatory risks.
- **Diversification and Resilience**: Diversification involves spreading risk across different markets, suppliers, or products. This strategy helps mitigate supply risks and financial risks by reducing dependency on a single source or market and increasing resilience to market shifts.
- **Financial Instruments**: Utilizing financial instruments, such as insurance, hedging, or credit lines, can help address financial risks. These tools provide a buffer against unforeseen economic challenges, including fluctuations in currency exchange rates or commodity prices.
- **Health and Disease Management**: This alternative focuses on minimizing health and disease risks, particularly those that affect livestock. Implementing proactive health measures, including vaccinations and biosecurity protocols, helps to ensure the well-being of animals and the stability of the SC.

The proposed methodology was applied to assess the effectiveness of these 11 criteria and 9 alternatives in mitigating risks within the LSC. The results of the evaluation showed that certain criteria, such as Environmental Risks and Supply Risks, were consistently identified as the most critical in maintaining the stability of the SC. These findings suggest that addressing environmental challenges, such as climate change, and ensuring reliable supply sources are central to reducing vulnerability.

Among the alternatives, Technology Integration Diversification, and Resilience were identified as the most impactful strategies for managing risks. Technology integration allows for greater efficiency and real-time monitoring of the SC, while diversification provides a safety net against market disruptions or supply shortages. Furthermore, Market Strategies Policy Advocacy, and Compliance were also found to be crucial for long-term sustainability. Businesses that actively engage with market trends and anticipate regulatory changes are better equipped to handle uncertainties and adapt to new challenges.

3.3 Discussion and Evaluation

The proposed methodology involves several structured steps to evaluate and rank alternatives for risk management in the LSC. Each step is crucial in transforming the decision matrix into actionable results. Below is a detailed explanation of the process, based on the specific formulas and techniques used.

- *Step 1: Building the Decision Matrix*

The first step involves creating the decision matrix with input from three experts who assess the alternatives based on a set of criteria. In this case, the decision matrix is built using Type-2 Neutrosophic Numbers (T2NNs), which help capture uncertainty and imprecision in the evaluation process. These numbers allow for a more accurate representation of expert opinions, especially when dealing with subjective or uncertain data. The decision matrix built using the T2NNs is shown in Table 1. This matrix forms the foundation for all subsequent calculations and evaluations in the methodology.

- *Step 2: Obtaining Crisp Values Using the Score Function*

Once the decision matrix is created, Equation (5) is applied to convert the T2NNs into crisp values. The score function is used for this conversion, which helps simplify the data for further processing. This is an essential step, as it transforms the initial decision matrix into clear, quantifiable values that can be analyzed effectively.

- *Step 3: Combining the Decision Matrix Using the Average Method*

In the next step, the decision matrix is combined by applying the average method. This method aggregates the input from the three experts to generate a consolidated decision matrix. By averaging the individual ratings, this step ensures that collective judgment is considered, thus reducing individual biases and uncertainties.

- *Step 4: Normalizing the Decision Matrix*

To ensure comparability across different criteria and alternatives, the decision matrix is normalized using Equation (8). Normalization standardizes the values so that all criteria are on a comparable scale, typically between 0 and 1. This step, as shown in Table 2, ensures that no single criterion disproportionately influences the results due to differences in measurement units or scale.

- *Step 5: Calculating Criteria Weights Using the Average Method*

The next step involves calculating the criteria weights using the average method. By averaging the normalized values, we can determine the relative importance of each criterion in the decision-making process. This step is crucial as it helps in identifying which risks (criteria) are most critical to the LSC's sustainability.

According to the results, Operational Risks were found to have the highest weights, meaning they are considered the most important criteria in this study. On the other hand, Infrastructure Risks were found to have the lowest weights, indicating that they are less significant in terms of risk management. This information is visually represented in Figure 1, which provides a clear depiction of the relative importance of each criterion.

- Step 6: Computing the Weighted Normalized Decision Matrix

The weighted normalized decision matrix is computed using Equation (9). This matrix reflects the importance of each criterion by multiplying the normalized values by the corresponding criteria weights. The result is a matrix that accounts for both the normalized performance of each alternative and the importance of the criteria, as shown in Table 3.

- *Step 7: Computing Score Values*

Once the weighted normalized decision matrix is obtained, Equation (10) is applied to compute the score values. These score values represent the overall performance of each alternative based on the weighted criteria. The higher the score, the better the alternative is in terms of risk management effectiveness.

- *Step 8: Ranking the Alternatives*

Finally, the alternatives are ranked based on the computed score values. As shown in Figure 2, the alternatives are ordered from the best to the worst, with the Health and Disease Management alternative emerging as the top-ranked option. This suggests that focusing on health and disease management is the most effective strategy for mitigating risks in the LSC.

The methodology applied in this study provides a clear and structured process for evaluating risk management strategies in the LSC. By using T2NNs and the average method, the study effectively integrates expert opinions, normalizes the data, and calculates the importance of different criteria. The results show that Health and Disease Management is the most effective alternative for managing risks, while Infrastructure Risks are considered the least significant in the context of this SC. These findings offer valuable insights into how risk management strategies can be optimized for better sustainability and resilience.

Table 1. The opinions of experts.

	RRX$_1$	**RRX$_2$**	**RRX$_3$**	**RRX$_4$**	**RRX$_5$**	**RRX$_6$**	**RRX$_7$**	**RRX$_8$**	**RRX$_9$**	**RRX$_{10}$**	**RRX$_{11}$**
RRY$_1$	((0.40,0.45,0.50), (0.40,0.45,0.50), (0.35,0.40,0.45))	((0.95,0.90,0.95), (0.10,0.10,0.05), (0.05,0.05,0.05))	((0.20,0.20,0.10), (0.65,0.80,0.85), (0.45,0.80,0.70))	((0.35,0.35,0.10), (0.50,0.75,0.80), (0.50,0.75,0.65))	((0.50,0.30,0.50), (0.50,0.35,0.45), (0.45,0.30,0.60))	((0.95,0.90,0.95), (0.10,0.10,0.05), (0.05,0.05,0.05))	((0.60,0.45,0.50), (0.20,0.15,0.25), (0.10,0.25,0.15))	((0.70,0.75,0.80), (0.15,0.20,0.25), (0.10,0.15,0.20))	((0.95,0.90,0.95), (0.10,0.10,0.05), (0.05,0.05,0.05))	((0.95,0.90,0.95), (0.10,0.10,0.05), (0.05,0.05,0.05))	((0.95,0.90,0.95), (0.10,0.10,0.05), (0.05,0.05,0.05))
RRY$_2$	((0.95,0.90,0.95), (0.10,0.10,0.05), (0.05,0.05,0.05))	((0.20,0.20,0.10), (0.65,0.80,0.85), (0.45,0.80,0.70))	((0.95,0.90,0.95), (0.10,0.10,0.05), (0.05,0.05,0.05))	((0.20,0.20,0.10), (0.65,0.80,0.85), (0.45,0.80,0.70))	((0.35,0.35,0.10), (0.50,0.75,0.80), (0.50,0.75,0.65))	((0.20,0.20,0.10), (0.65,0.80,0.85), (0.45,0.80,0.70))	((0.95,0.90,0.95), (0.10,0.10,0.05), (0.05,0.05,0.05))	((0.60,0.45,0.50), (0.20,0.15,0.25), (0.10,0.25,0.15))	((0.70,0.75,0.80), (0.15,0.20,0.25), (0.10,0.15,0.20))	((0.95,0.90,0.95), (0.10,0.10,0.05), (0.05,0.05,0.05))	((0.20,0.20,0.10), (0.65,0.80,0.85), (0.45,0.80,0.70))
RRY$_3$	((0.20,0.20,0.10), (0.65,0.80,0.85), (0.45,0.80,0.70))	((0.35,0.35,0.10), (0.50,0.75,0.80), (0.50,0.75,0.65))	((0.20,0.20,0.10), (0.65,0.80,0.85), (0.45,0.80,0.70))	((0.35,0.35,0.10), (0.50,0.75,0.80), (0.50,0.75,0.65))	((0.95,0.90,0.95), (0.10,0.10,0.05), (0.05,0.05,0.05))	((0.35,0.35,0.10), (0.50,0.75,0.80), (0.50,0.75,0.65))	((0.20,0.20,0.10), (0.65,0.80,0.85), (0.45,0.80,0.70))	((0.95,0.90,0.95), (0.10,0.10,0.05), (0.05,0.05,0.05))	((0.95,0.90,0.95), (0.10,0.10,0.05), (0.05,0.05,0.05))	((0.20,0.20,0.10), (0.65,0.80,0.85), (0.45,0.80,0.70))	((0.35,0.35,0.10), (0.50,0.75,0.80), (0.50,0.75,0.65))
RRY$_4$	((0.35,0.35,0.10), (0.50,0.75,0.80), (0.50,0.75,0.65))	((0.50,0.30,0.50), (0.50,0.35,0.45), (0.45,0.30,0.60))	((0.35,0.35,0.10), (0.50,0.75,0.80), (0.50,0.75,0.65))	((0.95,0.90,0.95), (0.10,0.10,0.05), (0.05,0.05,0.05))	((0.20,0.20,0.10), (0.65,0.80,0.85), (0.45,0.80,0.70))	((0.50,0.30,0.50), (0.50,0.35,0.45), (0.45,0.30,0.60))	((0.35,0.35,0.10), (0.50,0.75,0.80), (0.50,0.75,0.65))	((0.20,0.20,0.10), (0.65,0.80,0.85), (0.45,0.80,0.70))	((0.20,0.20,0.10), (0.65,0.80,0.85), (0.45,0.80,0.70))	((0.35,0.35,0.10), (0.50,0.75,0.80), (0.50,0.75,0.65))	((0.50,0.30,0.50), (0.50,0.35,0.45), (0.45,0.30,0.60))
RRY$_5$	((0.95,0.90,0.95), (0.10,0.10,0.05), (0.05,0.05,0.05))	((0.40,0.45,0.50), (0.40,0.45,0.50), (0.35,0.40,0.45))	((0.50,0.30,0.50), (0.50,0.35,0.45), (0.45,0.30,0.60))	((0.20,0.20,0.10), (0.65,0.80,0.85), (0.45,0.80,0.70))	((0.35,0.35,0.10), (0.50,0.75,0.80), (0.50,0.75,0.65))	((0.40,0.45,0.50), (0.40,0.45,0.50), (0.35,0.40,0.45))	((0.50,0.30,0.50), (0.50,0.35,0.45), (0.45,0.30,0.60))	((0.35,0.35,0.10), (0.50,0.75,0.80), (0.50,0.75,0.65))	((0.95,0.90,0.95), (0.10,0.10,0.05), (0.05,0.05,0.05))	((0.50,0.30,0.50), (0.50,0.35,0.45), (0.45,0.30,0.60))	((0.40,0.45,0.50), (0.40,0.45,0.50), (0.35,0.40,0.45))
RRY$_6$	((0.20,0.20,0.10), (0.65,0.80,0.85), (0.45,0.80,0.70))	((0.50,0.30,0.50), (0.50,0.35,0.45), (0.45,0.30,0.60))	((0.40,0.45,0.50), (0.40,0.45,0.50), (0.35,0.40,0.45))	((0.35,0.35,0.10), (0.50,0.75,0.80), (0.50,0.75,0.65))	((0.50,0.30,0.50), (0.50,0.35,0.45), (0.45,0.30,0.60))	((0.20,0.20,0.10), (0.65,0.80,0.85), (0.45,0.80,0.70))	((0.40,0.45,0.50), (0.40,0.45,0.50), (0.35,0.40,0.45))	((0.50,0.30,0.50), (0.50,0.35,0.45), (0.45,0.30,0.60))	((0.20,0.20,0.10), (0.65,0.80,0.85), (0.45,0.80,0.70))	((0.40,0.45,0.50), (0.40,0.45,0.50), (0.35,0.40,0.45))	((0.70,0.75,0.80), (0.15,0.20,0.25), (0.10,0.15,0.20))
RRY$_7$	((0.35,0.35,0.10), (0.50,0.75,0.80), (0.50,0.75,0.65))	((0.35,0.35,0.10), (0.50,0.75,0.80), (0.50,0.75,0.65))	((0.50,0.30,0.50), (0.50,0.35,0.45), (0.45,0.30,0.60))	((0.50,0.30,0.50), (0.50,0.35,0.45), (0.45,0.30,0.60))	((0.40,0.45,0.50), (0.40,0.45,0.50), (0.35,0.40,0.45))	((0.95,0.90,0.95), (0.10,0.10,0.05), (0.05,0.05,0.05))	((0.70,0.75,0.80), (0.15,0.20,0.25), (0.10,0.15,0.20))	((0.40,0.45,0.50), (0.40,0.45,0.50), (0.35,0.40,0.45))	((0.35,0.35,0.10), (0.50,0.75,0.80), (0.50,0.75,0.65))	((0.60,0.45,0.50), (0.20,0.15,0.25), (0.10,0.25,0.15))	((0.95,0.90,0.95), (0.10,0.10,0.05), (0.05,0.05,0.05))
RRY$_8$	((0.50,0.30,0.50), (0.50,0.35,0.45), (0.45,0.30,0.60))	((0.20,0.20,0.10), (0.65,0.80,0.85), (0.45,0.80,0.70))	((0.95,0.90,0.95), (0.10,0.10,0.05), (0.05,0.05,0.05))	((0.40,0.45,0.50), (0.40,0.45,0.50), (0.35,0.40,0.45))	((0.60,0.45,0.50), (0.20,0.15,0.25), (0.10,0.25,0.15))	((0.40,0.45,0.50), (0.40,0.45,0.50), (0.35,0.40,0.45))	((0.50,0.30,0.50), (0.50,0.35,0.45), (0.45,0.30,0.60))	((0.35,0.35,0.10), (0.50,0.75,0.80), (0.50,0.75,0.65))	((0.50,0.30,0.50), (0.50,0.35,0.45), (0.45,0.30,0.60))	((0.70,0.75,0.80), (0.15,0.20,0.25), (0.10,0.15,0.20))	((0.20,0.20,0.10), (0.65,0.80,0.85), (0.45,0.80,0.70))
RRY$_9$	((0.40,0.45,0.50), (0.40,0.45,0.50), (0.35,0.40,0.45))	((0.40,0.45,0.50), (0.40,0.45,0.50), (0.35,0.40,0.45))	((0.50,0.30,0.50), (0.50,0.35,0.45), (0.45,0.30,0.60))	((0.35,0.35,0.10), (0.50,0.75,0.80), (0.50,0.75,0.65))	((0.20,0.20,0.10), (0.65,0.80,0.85), (0.45,0.80,0.70))	((0.95,0.90,0.95), (0.10,0.10,0.05), (0.05,0.05,0.05))	((0.70,0.75,0.80), (0.15,0.20,0.25), (0.10,0.15,0.20))	((0.60,0.45,0.50), (0.20,0.15,0.25), (0.10,0.25,0.15))	((0.40,0.45,0.50), (0.40,0.45,0.50), (0.35,0.40,0.45))	((0.95,0.90,0.95), (0.10,0.10,0.05), (0.05,0.05,0.05))	((0.35,0.35,0.10), (0.50,0.75,0.80), (0.50,0.75,0.65))
	RRX$_1$	RRX$_2$	RRX$_3$	RRX$_4$	RRX$_5$	RRX$_6$	RRX$_7$	RRX$_8$	RRX$_9$	RRX$_{10}$	RRX$_{11}$
RRY$_1$	((0.50,0.30,0.50), (0.50,0.35,0.45), (0.45,0.30,0.60))	((0.95,0.90,0.95), (0.10,0.10,0.05), (0.05,0.05,0.05))	((0.50,0.30,0.50), (0.50,0.35,0.45), (0.45,0.30,0.60))	((0.35,0.35,0.10), (0.50,0.75,0.80), (0.50,0.75,0.65))	((0.50,0.30,0.50), (0.50,0.35,0.45), (0.45,0.30,0.60))	((0.40,0.45,0.50), (0.40,0.45,0.50), (0.35,0.40,0.45))	((0.50,0.30,0.50), (0.50,0.35,0.45), (0.45,0.30,0.60))	((0.50,0.30,0.50), (0.50,0.35,0.45), (0.45,0.30,0.60))	((0.95,0.90,0.95), (0.10,0.10,0.05), (0.05,0.05,0.05))	((0.50,0.30,0.50), (0.50,0.35,0.45), (0.45,0.30,0.60))	((0.20,0.20,0.10), (0.65,0.80,0.85), (0.45,0.80,0.70))
RRY$_2$	((0.40,0.45,0.50), (0.40,0.45,0.50), (0.35,0.40,0.45))	((0.50,0.30,0.50), (0.50,0.35,0.45), (0.45,0.30,0.60))	((0.40,0.45,0.50), (0.40,0.45,0.50), (0.35,0.40,0.45))	((0.50,0.30,0.50), (0.50,0.35,0.45), (0.45,0.30,0.60))	((0.50,0.30,0.50), (0.50,0.35,0.45), (0.45,0.30,0.60))	((0.50,0.30,0.50), (0.50,0.35,0.45), (0.45,0.30,0.60))	((0.40,0.45,0.50), (0.40,0.45,0.50), (0.35,0.40,0.45))	((0.40,0.45,0.50), (0.40,0.45,0.50), (0.35,0.40,0.45))	((0.70,0.75,0.80), (0.15,0.20,0.25), (0.10,0.15,0.20))	((0.40,0.45,0.50), (0.40,0.45,0.50), (0.35,0.40,0.45))	((0.35,0.35,0.10), (0.50,0.75,0.80), (0.50,0.75,0.65))
RRY$_3$	((0.60,0.45,0.50), (0.20,0.15,0.25), (0.10,0.25,0.15))	((0.40,0.45,0.50), (0.40,0.45,0.50), (0.35,0.40,0.45))	((0.60,0.45,0.50), (0.20,0.15,0.25), (0.10,0.25,0.15))	((0.40,0.45,0.50), (0.40,0.45,0.50), (0.35,0.40,0.45))	((0.40,0.45,0.50), (0.40,0.45,0.50), (0.35,0.40,0.45))	((0.40,0.45,0.50), (0.40,0.45,0.50), (0.35,0.40,0.45))	((0.60,0.45,0.50), (0.20,0.15,0.25), (0.10,0.25,0.15))	((0.60,0.45,0.50), (0.20,0.15,0.25), (0.10,0.25,0.15))	((0.95,0.90,0.95), (0.10,0.10,0.05), (0.05,0.05,0.05))	((0.60,0.45,0.50), (0.20,0.15,0.25), (0.10,0.25,0.15))	((0.50,0.30,0.50), (0.50,0.35,0.45), (0.45,0.30,0.60))
RRY$_4$	((0.70,0.75,0.80), (0.15,0.20,0.25), (0.10,0.15,0.20))	((0.60,0.45,0.50), (0.20,0.15,0.25), (0.10,0.25,0.15))	((0.70,0.75,0.80), (0.15,0.20,0.25), (0.10,0.15,0.20))	((0.60,0.45,0.50), (0.20,0.15,0.25), (0.10,0.25,0.15))	((0.60,0.45,0.50), (0.20,0.15,0.25), (0.10,0.25,0.15))	((0.60,0.45,0.50), (0.20,0.15,0.25), (0.10,0.25,0.15))	((0.70,0.75,0.80), (0.15,0.20,0.25), (0.10,0.15,0.20))	((0.70,0.75,0.80), (0.15,0.20,0.25), (0.10,0.15,0.20))	((0.20,0.20,0.10), (0.65,0.80,0.85), (0.45,0.80,0.70))	((0.70,0.75,0.80), (0.15,0.20,0.25), (0.10,0.15,0.20))	((0.40,0.45,0.50), (0.40,0.45,0.50), (0.35,0.40,0.45))
RRY$_5$	((0.95,0.90,0.95), (0.10,0.10,0.05), (0.05,0.05,0.05))	((0.70,0.75,0.80), (0.15,0.20,0.25), (0.10,0.15,0.20))	((0.95,0.90,0.95), (0.10,0.10,0.05), (0.05,0.05,0.05))	((0.70,0.75,0.80), (0.15,0.20,0.25), (0.10,0.15,0.20))	((0.50,0.30,0.50), (0.50,0.35,0.45), (0.45,0.30,0.60))	((0.70,0.75,0.80), (0.15,0.20,0.25), (0.10,0.15,0.20))	((0.95,0.90,0.95), (0.10,0.10,0.05), (0.05,0.05,0.05))	((0.50,0.30,0.50), (0.50,0.35,0.45), (0.45,0.30,0.60))	((0.50,0.30,0.50), (0.50,0.35,0.45), (0.45,0.30,0.60))	((0.50,0.30,0.50), (0.50,0.35,0.45), (0.45,0.30,0.60))	((0.60,0.45,0.50), (0.20,0.15,0.25), (0.10,0.25,0.15))
RRY$_6$	((0.60,0.45,0.50), (0.20,0.15,0.25), (0.10,0.25,0.15))	((0.95,0.90,0.95), (0.10,0.10,0.05), (0.05,0.05,0.05))	((0.40,0.45,0.50), (0.40,0.45,0.50), (0.35,0.40,0.45))	((0.95,0.90,0.95), (0.10,0.10,0.05), (0.05,0.05,0.05))	((0.40,0.45,0.50), (0.40,0.45,0.50), (0.35,0.40,0.45))	((0.95,0.90,0.95), (0.10,0.10,0.05), (0.05,0.05,0.05))	((0.40,0.45,0.50), (0.40,0.45,0.50), (0.35,0.40,0.45))	((0.40,0.45,0.50), (0.40,0.45,0.50), (0.35,0.40,0.45))	((0.40,0.45,0.50), (0.40,0.45,0.50), (0.35,0.40,0.45))	((0.40,0.45,0.50), (0.40,0.45,0.50), (0.35,0.40,0.45))	((0.70,0.75,0.80), (0.15,0.20,0.25), (0.10,0.15,0.20))
RRY$_7$	((0.70,0.75,0.80), (0.15,0.20,0.25), (0.10,0.15,0.20))	((0.35,0.35,0.10), (0.50,0.75,0.80), (0.50,0.75,0.65))	((0.50,0.30,0.50), (0.50,0.35,0.45), (0.45,0.30,0.60))	((0.60,0.45,0.50), (0.20,0.15,0.25), (0.10,0.25,0.15))	((0.60,0.45,0.50), (0.20,0.15,0.25), (0.10,0.25,0.15))	((0.95,0.90,0.95), (0.10,0.10,0.05), (0.05,0.05,0.05))	((0.60,0.45,0.50), (0.20,0.15,0.25), (0.10,0.25,0.15))	((0.60,0.45,0.50), (0.20,0.15,0.25), (0.10,0.25,0.15))	((0.60,0.45,0.50), (0.20,0.15,0.25), (0.10,0.25,0.15))	((0.60,0.45,0.50), (0.20,0.15,0.25), (0.10,0.25,0.15))	((0.95,0.90,0.95), (0.10,0.10,0.05), (0.05,0.05,0.05))
RRY$_8$	((0.95,0.90,0.95), (0.10,0.10,0.05), (0.05,0.05,0.05))	((0.20,0.20,0.10), (0.65,0.80,0.85), (0.45,0.80,0.70))	((0.95,0.90,0.95), (0.10,0.10,0.05), (0.05,0.05,0.05))	((0.70,0.75,0.80), (0.15,0.20,0.25), (0.10,0.15,0.20))	((0.70,0.75,0.80), (0.15,0.20,0.25), (0.10,0.15,0.20))	((0.40,0.45,0.50), (0.40,0.45,0.50), (0.35,0.40,0.45))	((0.70,0.75,0.80), (0.15,0.20,0.25), (0.10,0.15,0.20))	((0.70,0.75,0.80), (0.15,0.20,0.25), (0.10,0.15,0.20))	((0.70,0.75,0.80), (0.15,0.20,0.25), (0.10,0.15,0.20))	((0.70,0.75,0.80), (0.15,0.20,0.25), (0.10,0.15,0.20))	((0.20,0.20,0.10), (0.65,0.80,0.85), (0.45,0.80,0.70))
RRY$_9$	((0.60,0.45,0.50), (0.20,0.15,0.25), (0.10,0.25,0.15))	((0.40,0.45,0.50), (0.40,0.45,0.50), (0.35,0.40,0.45))	((0.50,0.30,0.50), (0.50,0.35,0.45), (0.45,0.30,0.60))	((0.95,0.90,0.95), (0.10,0.10,0.05), (0.05,0.05,0.05))	((0.95,0.90,0.95), (0.10,0.10,0.05), (0.05,0.05,0.05))	((0.95,0.90,0.95), (0.10,0.10,0.05), (0.05,0.05,0.05))	((0.95,0.90,0.95), (0.10,0.10,0.05), (0.05,0.05,0.05))	((0.95,0.90,0.95), (0.10,0.10,0.05), (0.05,0.05,0.05))	((0.95,0.90,0.95), (0.10,0.10,0.05), (0.05,0.05,0.05))	((0.95,0.90,0.95), (0.10,0.10,0.05), (0.05,0.05,0.05))	((0.35,0.35,0.10), (0.50,0.75,0.80), (0.50,0.75,0.65))
	RRX$_1$	RRX$_2$	RRX$_3$	RRX$_4$	RRX$_5$	RRX$_6$	RRX$_7$	RRX$_8$	RRX$_9$	RRX$_{10}$	RRX$_{11}$
RRY$_1$	((0.40,0.45,0.50), (0.40,0.45,0.50), (0.35,0.40,0.45))	((0.95,0.90,0.95), (0.10,0.10,0.05), (0.05,0.05,0.05))	((0.20,0.20,0.10), (0.65,0.80,0.85), (0.45,0.80,0.70))	((0.35,0.35,0.10), (0.50,0.75,0.80), (0.50,0.75,0.65))	((0.50,0.30,0.50), (0.50,0.35,0.45), (0.45,0.30,0.60))	((0.40,0.45,0.50), (0.40,0.45,0.50), (0.35,0.40,0.45))	((0.60,0.45,0.50), (0.20,0.15,0.25), (0.10,0.25,0.15))	((0.70,0.75,0.80), (0.15,0.20,0.25), (0.10,0.15,0.20))	((0.95,0.90,0.95), (0.10,0.10,0.05), (0.05,0.05,0.05))	((0.95,0.90,0.95), (0.10,0.10,0.05), (0.05,0.05,0.05))	((0.20,0.20,0.10), (0.65,0.80,0.85), (0.45,0.80,0.70))
RRY$_2$	((0.60,0.45,0.50), (0.20,0.15,0.25), (0.10,0.25,0.15))	((0.70,0.75,0.80), (0.15,0.20,0.25), (0.10,0.15,0.20))	((0.95,0.90,0.95), (0.10,0.10,0.05), (0.05,0.05,0.05))	((0.20,0.20,0.10), (0.65,0.80,0.85), (0.45,0.80,0.70))	((0.35,0.35,0.10), (0.50,0.75,0.80), (0.50,0.75,0.65))	((0.50,0.30,0.50), (0.50,0.35,0.45), (0.45,0.30,0.60))	((0.40,0.45,0.50), (0.40,0.45,0.50), (0.35,0.40,0.45))	((0.60,0.45,0.50), (0.20,0.15,0.25), (0.10,0.25,0.15))	((0.70,0.75,0.80), (0.15,0.20,0.25), (0.10,0.15,0.20))	((0.95,0.90,0.95), (0.10,0.10,0.05), (0.05,0.05,0.05))	((0.35,0.35,0.10), (0.50,0.75,0.80), (0.50,0.75,0.65))
RRY$_3$	((0.40,0.45,0.50), (0.40,0.45,0.50), (0.35,0.40,0.45))	((0.70,0.75,0.80), (0.15,0.20,0.25), (0.10,0.15,0.20))	((0.20,0.20,0.10), (0.65,0.80,0.85), (0.45,0.80,0.70))	((0.35,0.35,0.10), (0.50,0.75,0.80), (0.50,0.75,0.65))	((0.50,0.30,0.50), (0.50,0.35,0.45), (0.45,0.30,0.60))	((0.40,0.45,0.50), (0.40,0.45,0.50), (0.35,0.40,0.45))	((0.60,0.45,0.50), (0.20,0.15,0.25), (0.10,0.25,0.15))	((0.70,0.75,0.80), (0.15,0.20,0.25), (0.10,0.15,0.20))	((0.95,0.90,0.95), (0.10,0.10,0.05), (0.05,0.05,0.05))	((0.20,0.20,0.10), (0.65,0.80,0.85), (0.45,0.80,0.70))	((0.50,0.30,0.50), (0.50,0.35,0.45), (0.45,0.30,0.60))
RRY$_4$	((0.50,0.30,0.50), (0.50,0.35,0.45), (0.45,0.30,0.60))	((0.60,0.45,0.50), (0.20,0.15,0.25), (0.10,0.25,0.15))	((0.70,0.75,0.80), (0.15,0.20,0.25), (0.10,0.15,0.20))	((0.95,0.90,0.95), (0.10,0.10,0.05), (0.05,0.05,0.05))	((0.20,0.20,0.10), (0.65,0.80,0.85), (0.45,0.80,0.70))	((0.35,0.35,0.10), (0.50,0.75,0.80), (0.50,0.75,0.65))	((0.50,0.30,0.50), (0.50,0.35,0.45), (0.45,0.30,0.60))	((0.40,0.45,0.50), (0.40,0.45,0.50), (0.35,0.40,0.45))	((0.20,0.20,0.10), (0.65,0.80,0.85), (0.45,0.80,0.70))	((0.35,0.35,0.10), (0.50,0.75,0.80), (0.50,0.75,0.65))	((0.40,0.45,0.50), (0.40,0.45,0.50), (0.35,0.40,0.45))
RRY$_5$	((0.35,0.35,0.10), (0.50,0.75,0.80), (0.50,0.75,0.65))	((0.40,0.45,0.50), (0.40,0.45,0.50), (0.35,0.40,0.45))	((0.60,0.45,0.50), (0.20,0.15,0.25), (0.10,0.25,0.15))	((0.20,0.20,0.10), (0.65,0.80,0.85), (0.45,0.80,0.70))	((0.35,0.35,0.10), (0.50,0.75,0.80), (0.50,0.75,0.65))	((0.50,0.30,0.50), (0.50,0.35,0.45), (0.45,0.30,0.60))	((0.40,0.45,0.50), (0.40,0.45,0.50), (0.35,0.40,0.45))	((0.60,0.45,0.50), (0.20,0.15,0.25), (0.10,0.25,0.15))	((0.35,0.35,0.10), (0.50,0.75,0.80), (0.50,0.75,0.65))	((0.50,0.30,0.50), (0.50,0.35,0.45), (0.45,0.30,0.60))	((0.60,0.45,0.50), (0.20,0.15,0.25), (0.10,0.25,0.15))
RRY$_6$	((0.20,0.20,0.10), (0.65,0.80,0.85), (0.45,0.80,0.70))	((0.50,0.30,0.50), (0.50,0.35,0.45), (0.45,0.30,0.60))	((0.40,0.45,0.50), (0.40,0.45,0.50), (0.35,0.40,0.45))	((0.50,0.30,0.50), (0.50,0.35,0.45), (0.45,0.30,0.60))	((0.35,0.35,0.10), (0.50,0.75,0.80), (0.50,0.75,0.65))	((0.20,0.20,0.10), (0.65,0.80,0.85), (0.45,0.80,0.70))	((0.95,0.90,0.95), (0.10,0.10,0.05), (0.05,0.05,0.05))	((0.70,0.75,0.80), (0.15,0.20,0.25), (0.10,0.15,0.20))	((0.50,0.30,0.50), (0.50,0.35,0.45), (0.45,0.30,0.60))	((0.40,0.45,0.50), (0.40,0.45,0.50), (0.35,0.40,0.45))	((0.70,0.75,0.80), (0.15,0.20,0.25), (0.10,0.15,0.20))
RRY$_7$	((0.95,0.90,0.95), (0.10,0.10,0.05), (0.05,0.05,0.05))	((0.35,0.35,0.10), (0.50,0.75,0.80), (0.50,0.75,0.65))	((0.50,0.30,0.50), (0.50,0.35,0.45), (0.45,0.30,0.60))	((0.35,0.35,0.10), (0.50,0.75,0.80), (0.50,0.75,0.65))	((0.20,0.20,0.10), (0.65,0.80,0.85), (0.45,0.80,0.70))	((0.95,0.90,0.95), (0.10,0.10,0.05), (0.05,0.05,0.05))	((0.70,0.75,0.80), (0.15,0.20,0.25), (0.10,0.15,0.20))	((0.60,0.45,0.50), (0.20,0.15,0.25), (0.10,0.25,0.15))	((0.40,0.45,0.50), (0.40,0.45,0.50), (0.35,0.40,0.45))	((0.60,0.45,0.50), (0.20,0.15,0.25), (0.10,0.25,0.15))	((0.95,0.90,0.95), (0.10,0.10,0.05), (0.05,0.05,0.05))
RRY$_8$	((0.70,0.75,0.80), (0.15,0.20,0.25), (0.10,0.15,0.20))	((0.20,0.20,0.10), (0.65,0.80,0.85), (0.45,0.80,0.70))	((0.95,0.90,0.95), (0.10,0.10,0.05), (0.05,0.05,0.05))	((0.70,0.75,0.80), (0.15,0.20,0.25), (0.10,0.15,0.20))	((0.60,0.45,0.50), (0.20,0.15,0.25), (0.10,0.25,0.15))	((0.40,0.45,0.50), (0.40,0.45,0.50), (0.35,0.40,0.45))	((0.50,0.30,0.50), (0.50,0.35,0.45), (0.45,0.30,0.60))	((0.35,0.35,0.10), (0.50,0.75,0.80), (0.50,0.75,0.65))	((0.20,0.20,0.10), (0.65,0.80,0.85), (0.45,0.80,0.70))	((0.70,0.75,0.80), (0.15,0.20,0.25), (0.10,0.15,0.20))	((0.20,0.20,0.10), (0.65,0.80,0.85), (0.45,0.80,0.70))
RRY$_9$	((0.60,0.45,0.50), (0.20,0.15,0.25), (0.10,0.25,0.15))	((0.40,0.45,0.50), (0.40,0.45,0.50), (0.35,0.40,0.45))	((0.50,0.30,0.50), (0.50,0.35,0.45), (0.45,0.30,0.60))	((0.35,0.35,0.10), (0.50,0.75,0.80), (0.50,0.75,0.65))	((0.20,0.20,0.10), (0.65,0.80,0.85), (0.45,0.80,0.70))	((0.95,0.90,0.95), (0.10,0.10,0.05), (0.05,0.05,0.05))	((0.70,0.75,0.80), (0.15,0.20,0.25), (0.10,0.15,0.20))	((0.60,0.45,0.50), (0.20,0.15,0.25), (0.10,0.25,0.15))	((0.40,0.45,0.50), (0.40,0.45,0.50), (0.35,0.40,0.45))	((0.95,0.90,0.95), (0.10,0.10,0.05), (0.05,0.05,0.05))	((0.35,0.35,0.10), (0.50,0.75,0.80), (0.50,0.75,0.65))

Table 2. The normalized decision matrix.

	RRX$_1$	RRX$_2$	RRX$_3$	RRX$_4$	RRX$_5$	RRX$_6$	RRX$_7$	RRX$_8$	RRX$_9$	RRX$_{10}$	RRX$_{11}$
RRY$_1$	0.15289	0.298644	0.094548	0.116521	0.221013	0.179085	0.16074	0.188222	0.23609	0.188684	0.163429
RRY$_2$	0.208523	0.167402	0.226127	0.125969	0.160205	0.115527	0.165225	0.172721	0.20327	0.189344	0.099415
RRY$_3$	0.142084	0.175883	0.111882	0.144864	0.278897	0.123378	0.13694	0.215902	0.23609	0.093682	0.158095
RRY$_4$	0.156893	0.208024	0.180429	0.32332	0.166052	0.138333	0.135215	0.139137	0.060346	0.112155	0.185252
RRY$_5$	0.208123	0.199989	0.20446	0.16061	0.160205	0.166748	0.164535	0.136553	0.149277	0.12469	0.226958
RRY$_6$	0.113667	0.212042	0.151277	0.22202	0.191778	0.125995	0.165225	0.164602	0.109752	0.126669	0.279333
RRY$_7$	0.195716	0.099102	0.148913	0.194202	0.207565	0.250121	0.191095	0.172721	0.131279	0.168233	0.324434
RRY$_8$	0.216528	0.076335	0.263553	0.268734	0.311055	0.143567	0.153152	0.125481	0.132337	0.190004	0.082927
RRY$_9$	0.187311	0.171419	0.148913	0.194727	0.19704	0.250121	0.209376	0.207782	0.169039	0.220682	0.10766

Table 3. The weighted normalized decision matrix.

	RRX_1	RRX_2	RRX_3	RRX_4	RRX_5	RRX_6	RRX_7	RRX_8	RRX_9	RRX_{10}	RRX_{11}
RRY_1	0.014346	0.025555	0.008719	0.009229	0.016997	0.016978	0.016392	0.018443	0.022674	0.019205	0.013022
RRY_2	0.019566	0.014324	0.020853	0.009978	0.01232	0.010953	0.016849	0.016924	0.019522	0.019272	0.007922
RRY_3	0.013332	0.01505	0.010317	0.011474	0.021448	0.011697	0.013964	0.021155	0.022674	0.009536	0.012597
RRY_4	0.014721	0.0178	0.016639	0.025609	0.01277	0.013115	0.013789	0.013634	0.005796	0.011416	0.014761
RRY_5	0.019529	0.017113	0.018855	0.012721	0.01232	0.015809	0.016778	0.01338	0.014336	0.012692	0.018084
RRY_6	0.010666	0.018144	0.01395	0.017585	0.014748	0.011945	0.016849	0.016129	0.010541	0.012893	0.022257
RRY_7	0.018364	0.00848	0.013732	0.015382	0.015962	0.023713	0.019487	0.016924	0.012608	0.017124	0.025851
RRY_8	0.020317	0.006532	0.024304	0.021285	0.023921	0.013611	0.015618	0.012295	0.01271	0.01934	0.006608
RRY_9	0.017576	0.014668	0.013732	0.015424	0.015153	0.023713	0.021351	0.02036	0.016234	0.022462	0.008578

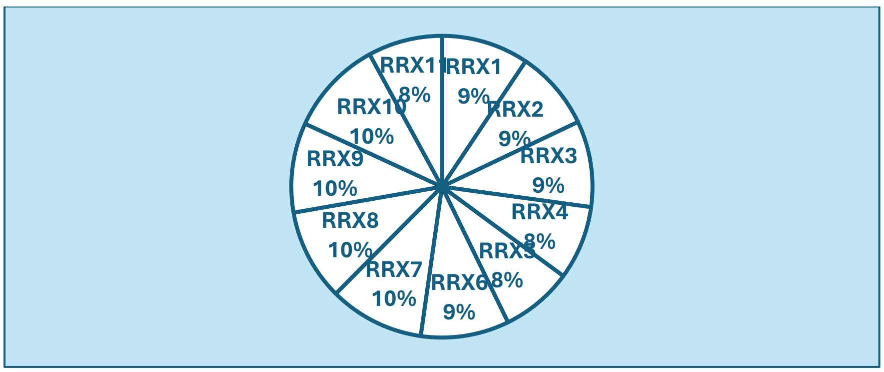

Figure 1. The criteria weights.

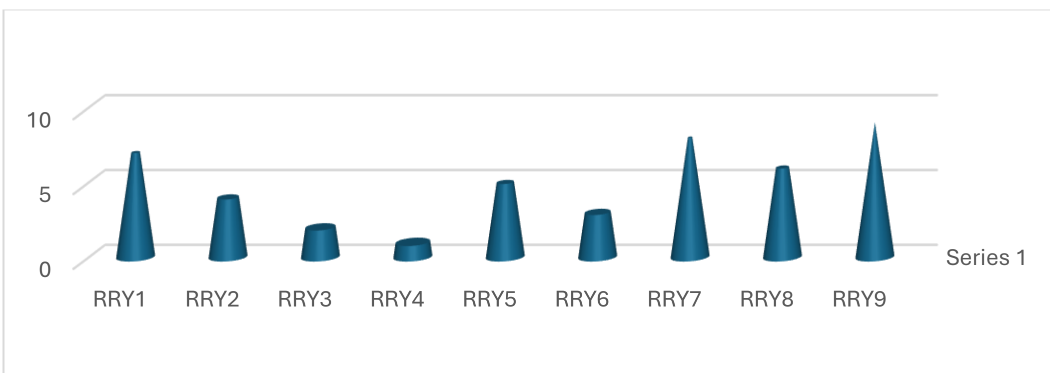

Figure 2. The rank of alternatives.

4. Sensitivity Analysis

In this section, we conduct a sensitivity analysis to evaluate how changes in the criteria weights affect the ranking of the alternatives. Sensitivity analysis is crucial in decision-making processes, as it helps to understand the robustness of the results under varying conditions. By altering the weights assigned to the criteria, we can assess whether the proposed method provides consistent and reliable rankings or if it is highly sensitive to changes in these weights.

4.1 Altering Criteria Weights Across Different Cases

To perform the sensitivity analysis, we systematically change the criteria weights across 12 different cases, as shown in Figure 3. Each case represents a different set of criteria weights, reflecting various possible scenarios or priorities that might be assigned to the factors influencing risk management in the LSC. The idea behind this approach is to explore how the rankings of the alternatives change when the importance of different criteria is adjusted. These changes might occur due to shifting market conditions, changes in policy or regulations, or evolving priorities within the SC.

4.2 Applying the Proposed Method Under Different Weights

After altering the criteria weights in the 12 different cases, we apply the proposed method to compute the rankings of the alternatives under each set of weights. The results of these calculations are shown in Figure 4. For each case, the ranking of the alternatives is updated based on the new weightings, and the resulting rankings are compared.

4.3 Analysis of Stability

The key observation from the sensitivity analysis is that the proposed method is stable under different criteria weights. This means that, despite the changes in the importance given to various risk factors, the overall ranking of the alternatives remains consistent. Specifically, Health and Disease Management continues to rank as the top alternative in most cases, indicating its robustness as a critical risk mitigation strategy in the LSC. This stability highlights the reliability and generalizability of the method in real-world applications, where the relative importance of different criteria may fluctuate over time. The consistency of the rankings under different weight scenarios suggests that the proposed method provides a solid basis for decision-making, even when external factors influence the criteria weights.

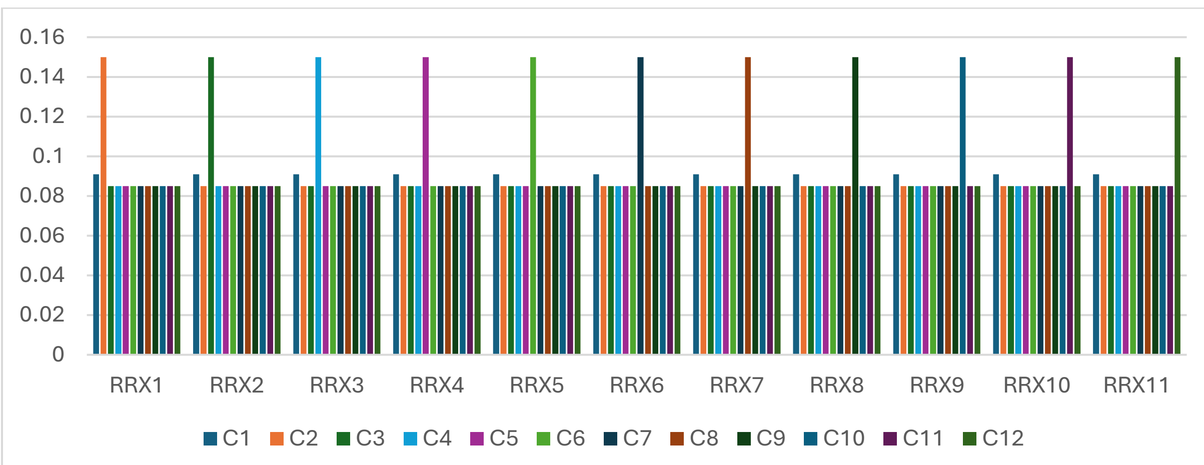

Figure 3. The different criteria weights.

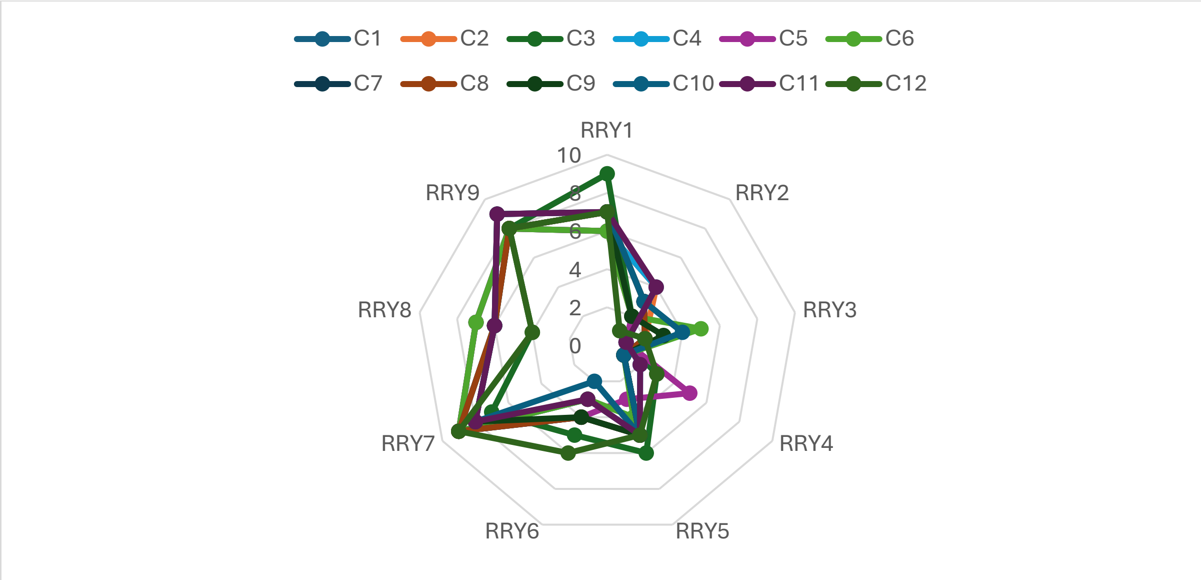

Figure 4. The different ranks of alternatives.

5. Comparative Analysis

In this section, we conduct a comparative analysis between the proposed method and other established Multi-Criteria Decision-Making (MCDM) methods. The goal of this analysis is to evaluate the robustness and effectiveness of the proposed method in comparison to widely used MCDM techniques such as TOPSIS, MABAC, and VIKOR. By applying the same set of alternatives and criteria across these methods, we can determine how well the proposed method performs relative to the others in terms of ranking alternatives and handling decision complexities.

To compare the methods, we used the same set of criteria and alternatives that were evaluated in the proposed method. The decision matrix was constructed using the same T2NNs for the proposed method and the standard input for the other MCDM methods. After processing the data through each method, the rankings of the alternatives were obtained. We then compared the rankings produced by each method to assess how each method handled the decision problem. Key points of comparison included the consistency of rankings, the ability to handle uncertainty, and the overall stability of the results across different weighting schemes.

The results of the comparative analysis are shown in Figure 5. From the analysis, the proposed method demonstrated several advantages over the traditional MCDM methods:

- The proposed method showed a high degree of stability and consistency across varying criteria weights and decision scenarios. While the other methods (TOPSIS, MABAC, and VIKOR) sometimes produced different rankings when criteria weights were altered, the proposed method consistently ranked Health and Disease Management as the best alternative. This indicates that the proposed method is less sensitive to changes in criteria weights, making it more robust in dynamic decision-making environments.
- The proposed method, based on T2NNs, was particularly effective at capturing and handling uncertainty and imprecision in the decision-making process. While the other methods are effective for

crisp data, they struggle to handle the uncertainty present in real-world decision problems as well as the proposed method does.

- The proposed method accounted for a wider range of risk factors and provided a more comprehensive evaluation of alternatives, whereas methods like TOPSIS, MABAC, and VIKOR tend to focus on fewer risk categories or handle them with less granularity.

Figure 5 clearly illustrates the comparative performance of the methods, showing how the alternatives were ranked by each method. The ranking results confirm that, while all methods were able to identify Health and Disease Management as a high-ranking alternative, the proposed method was the most consistent and stable across different scenarios and changes in criteria weights.

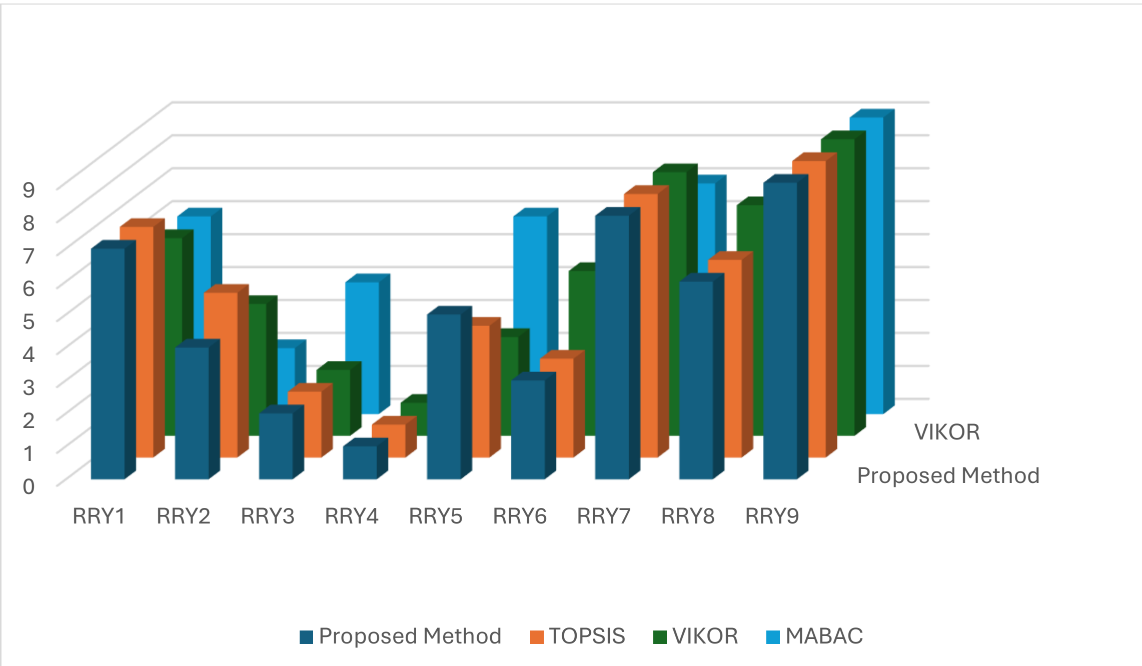

Figure 5. Comparative analysis.

6. Managerial Implications

Evaluating risks within the LSC is crucial for managers, as it provides them with valuable insights into potential vulnerabilities and allows them to design strategies that mitigate these risks effectively. By utilizing the findings from risk assessments, managers can enhance decision-making, streamline operations, and ensure sustainability across the SC. Below are the key managerial implications grouped into focus areas that will help guide practical applications of the results from this study.

Risk assessment provides managers with data-driven insights that allow them to make informed decisions on where to focus their risk mitigation efforts. For example, the analysis may reveal significant vulnerabilities in areas such as transportation risks or disease control, enabling managers to prioritize actions in these areas. For instance, if transportation risks are found to be high, managers could consider investing in more reliable vehicles, optimizing routes, or creating contingency plans for transportation disruptions. Similarly, for disease-related risks, managers may decide to invest in enhanced biosecurity protocols, vaccination programs, or partnerships with veterinary experts to mitigate potential outbreaks.

By understanding which risks are most critical, managers can implement targeted interventions that provide the highest return in terms of risk reduction.

By identifying and assessing operational risks, such as feed shortages, logistical challenges, or labor-related issues, managers can take proactive steps to minimize disruptions in the SC. For example, if feed shortages are identified as a potential risk, managers might explore diversifying feed suppliers, establishing contingency plans, or even adjusting inventory management practices to mitigate such shortages. If infrastructure risks related to storage or processing facilities are highlighted, investing in infrastructure upgrades or creating backup facilities could ensure operational continuity. Proactively addressing these risks helps maintain a smoother flow of operations, reduces downtime, and ensures that critical SC activities are not interrupted.

Risk assessment aids managers in making better decisions regarding resource allocation by highlighting the severity and likelihood of various risks. Resources such as vaccines, feed, labor, and financial support can be allocated more effectively based on the risk priorities. For instance, if health and disease management risks are found to be a major concern, resources may be directed toward improving animal health monitoring systems, vaccine procurement, and biosecurity measures. Similarly, in the case of transportation risks, managers may choose to allocate resources toward improving fleet management, upgrading equipment, or negotiating better contracts with logistics providers. By aligning resource distribution with identified risks, managers can ensure that the right resources are available at the right time, which ultimately contributes to more efficient and resilient SC operations.

In the context of sustainability, risk assessment empowers managers to make decisions that not only mitigate immediate risks but also promote long-term resilience. For example, focusing on environmental risks and adopting sustainable practices in sourcing, production, and waste management can help mitigate the impact of climate change and environmental degradation. Similarly, financial risks may lead managers to adopt more robust financial strategies, such as hedging, diversifying revenue streams, or creating financial reserves to weather economic fluctuations. By taking a proactive approach to managing these risks, managers can build a more sustainable and resilient LSC that is better prepared for future challenges.

Lastly, implementing risk management strategies requires continuous monitoring and adjustment. Managers should establish regular reviews of the risk landscape, incorporating new data, technologies, and evolving market conditions into the risk assessment process. This ongoing evaluation will allow them to stay ahead of emerging risks, refine existing strategies, and adapt to changing circumstances, ensuring that the SC remains resilient in the long run.

7. Conclusions

This study used the MCDM methodology for risk management in LSC risks. We used the T2NSs to deal with the uncertainty problem in the decision-making problem. We used the MOOSRA method to rank alternatives. 11 criteria and nine alternatives were collected from the previous study. Three experts are invited to evaluate the criteria and alternatives. Then we normalized the decision matrix between criteria and alternatives. The results show that operational risks have the highest weights of criteria. The alternatives Health and Disease Management has the highest alternatives. We conducted a sensitivity analysis to show the stability of the rank of alternatives under different weights. We proposed 12 cases in the criteria weights. We show the rank of alternatives is stable. We conducted a comparative analysis between the proposed method and other MCDM methods. We proposed the method is robust compared with other MCDM methods.

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