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An Effective Decision-Making Framework for Evaluating the Intelligent Logistics Development Scenarios Performance

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Abstract: This research was conducted with the intention of determining which scenario for the construction of an intelligent reverse logistics system had the most potential for success. This selection would then be used as a reference point for decision-making throughout the process of constructing environmentally friendly closed supply chains and circular economies. The research includes the definition of four different development scenarios, each of which is then reviewed by representatives of the key stakeholders based on a comprehensive list of eight sub-indicators that are categorized under the four primary dimensions. In order to tackle the issue that was specified, a brand new multi-criteria decision-making (MCDM) framework was constructed. This model included using the Combinative Distance based Assessment (CODAS) technique in a neutrosophic environment and applying the type-2 neutrosophic numbers (T2NNs). The utilization of the developed framework led to the identification of the scenario that optimally reconciles the widespread implementation of Industry 4.0 technologies with the requisite resources.

Keywords: Reverse Logistics; Intelligent Logistics; Industry 4.0; MCDM; Supply chain; T2NNs; CODAS.

1. Introduction

The absence of raw resources, the increasing degradation of the environment, a rising degree of social responsibility, environmental restrictions, and shifting market conditions have brought the topic of reverse logistics to the forefront of many ongoing research on sustainability [1]. The development of reverse logistics systems is the most important requirement and a precondition for the establishment of a closed-loop supply chain, which is a type of supply chain that is analogous to the idea of a circular economy. In the beginning, public awareness was the driving force behind research on closed-loop supply chains and reverse logistics, which means that the difficulties caused by return flows to ordinary people and their environment were the impetus for this line of inquiry [2]. These issues become the focus of the legislative authorities, which pass a variety of laws and directives to regulate this area as a response to the growing consumer society, the decrease in the product lifetime, and the pressure from the general public to find solutions to the problems caused by end-of-life products [3]. Finally, reverse logistics and closed-loop supply chains are seen as the regions in which many actors in the supply chain have the potential to make money for themselves. A market that is centered on reverse logistics is now in the process of developing as a result of the emergence of new demands for the supply of services as well as new suppliers of those services [4]. As a result, the construction of a sustainable reverse logistics system that is in accordance with the objectives and interests of the primary stakeholders, including the service providers, service users, administrations, and people, becomes the goal. They gain advantages as a result of this type of system as a result of a decrease in the amount of waste that is disposed of, an increase in the amount of product value and energy that is recovered, an extension of the product's life cycle, the extraction of materials and their subsequent recycling, the generation of competitive advantage, an acceleration of the return on investment, an improvement in customer relations, and a decrease in the amount of emissions produced by transportation [5,6]. As a result, the focus of this research is on the formulation and analysis of potential futures for the development of intelligent reverse logistics systems [4]. These futures are to be conceived with the level of advancement of Industry 4.0 technologies, the scope of their potential applications, and the current state of social, economic, technical, service quality, and environmental trends in mind.

As a consequence of this, the scenario that offers the greatest balance between the extensive use of Industry 4.0 technologies and the required resources for its development and implementation is chosen as the optimal option. It is feasible to draw the conclusion from the findings that the broadest possible use of technologies related to Industry 4.0 does not necessarily guarantee the most acceptable development scenarios and that the choice ought to be taken by reaching a compromise between the interests of all stakeholders. In this work, a unique multi-criteria decision-making (MCDM) model has been constructed in order to answer the issue that has been specified [7–9]. This model incorporates the Combinative Distance based Assessment (CODAS) [10] approach inside a neutrosophic environment. The neutrosophic set is applied in various filed as: [11-17]

The residue sections of the study are organized as follows: Section 2 develops the suggested framework for determining the suitable reverse logistics development scenario. Section 3 applies the suggested framework and analysis of the findings. Section 4 concludes the study.

2. Suggested Framework

In this section, the proposed approach to solve the problem of selecting and defining the best scenarios for the development of intelligent logistics services is introduced. The proposed framework is divided into three stages. The first stage is related to studying the problem and defining the main goal. In addition, identifying the committee involved with the authors in studying the problem and expressing their opinions on the main dimensions, and evaluating the alternatives. The second stage is related to evaluating the dimensions and determining the weights, whether for the main dimensions or the sub-indicators. The third stage is related to evaluating and ranking the alternatives selected for the study using the CODAS method. Also, the study and its details were conducted in a neutrosophic environment and by applying T2NNs. Figure 1 presents the steps of the proposed approach and details of the study procedure.

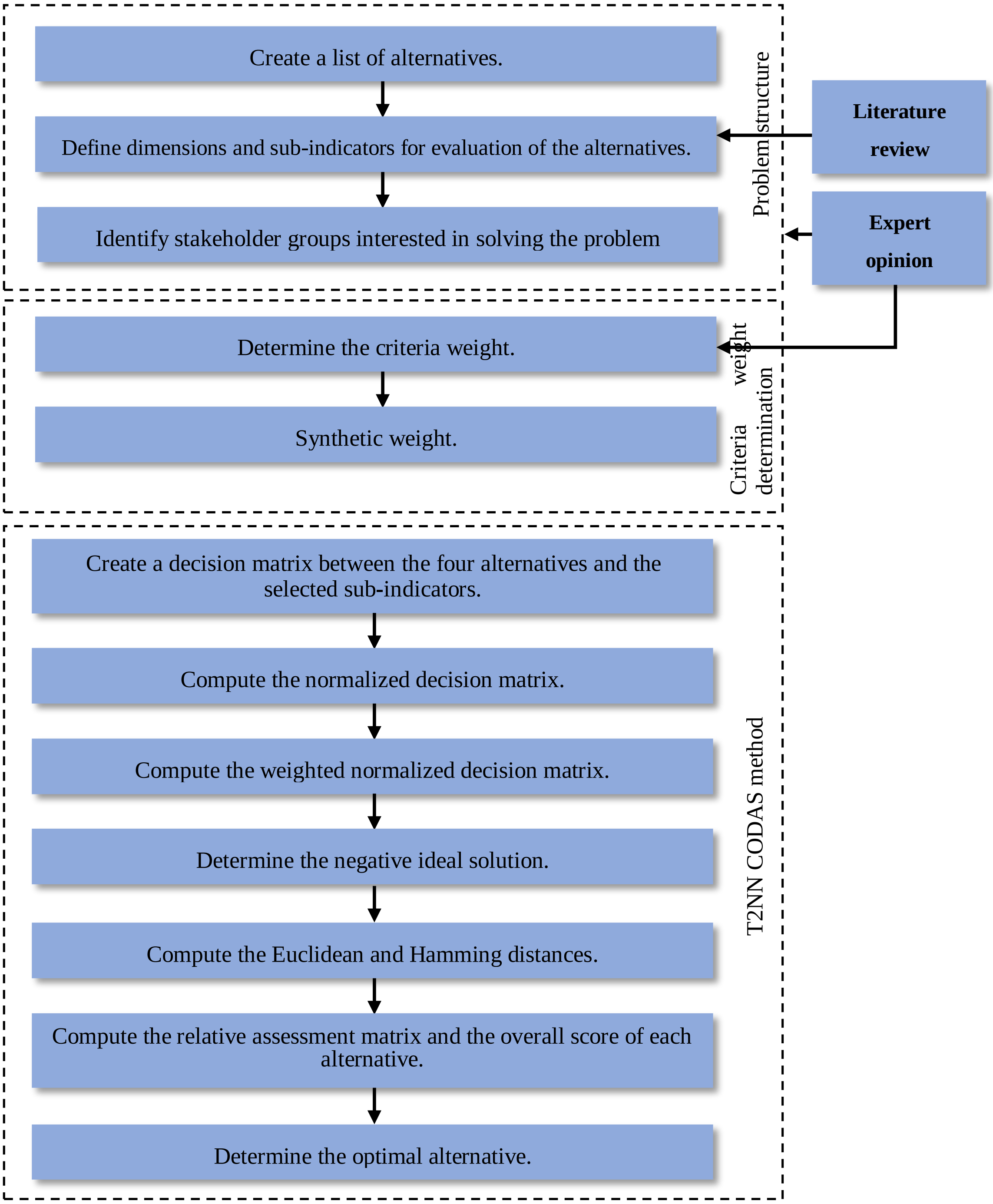

Figure 1. Research framework.

Step 1. The issue is considered in detail and the participating consultants are determined as shown in Table 1. The participating consultants give their opinions on the problem and define the dimensions and available scenarios. Suppose a set of m substitutes is represented by $A = \{A_1, \dots, A_i, \dots\ A_m\}$ and a set of n dimensions is denoted by $D = \{D_1, \dots, D_n, \dots, D_n\}$. Let consultants $= \{Consultant_1, \dots, Consultant_e, \dots, Consultant_k\}$ be a set of consultants who offered their valuation report for each substitute $A_i\,(i = 1, 2\dots\ m)$ against their dimensions $D_j\,(j = 1, 2\dots\ n)$. Let $w = (\mathrm{w}_1, \mathrm{w}_2, \dots, \mathrm{w}_e)^T$ be the weight vector for consultants $Consultant_e(e = 1, 2\dots\ k)$ such that $\sum_{j=1}^{n} \mathrm{w}_l = 1$.

Step 2. The issue is considered in detail and the participating consultants are determined as shown in Table 1. The participating consultants give their opinions on the problem and define the dimensions and available scenarios.

Table 1. Particulars on the members of the panel of consultants.

Consultants	Experience	Occupation	Academic degree	Gender
Consultant_1	18	Industry	M.Sc.	Male
Consultant_2	25	Academia	Ph.D.	Male
Consultant_3	18	Industry	M.Sc.	Female
Consultant_4	25	Industry	Ph.D.	Female

Step 2. A set of linguistic variables and their equivalent T2NNs are identified as presented in Table 2, for consultants to use in evaluating the main dimensions and their sub-indicators, in addition to evaluating and arranging the selected alternatives.

Table 2. T2NN linguistic terms for weighing dimensions and alternatives.

Linguistic terms	Abridgements	Type-2 neutrosophic number
Exceedingly little	ELE	$\langle(0.20, 0.20, 0.10); (0.65, 0.80, 0.85); (0.45, 0.80, 0.70)\rangle$
Little	LLE	$\langle(0.35, 0.35, 0.10); (0.50, 0.75, 0.80); (0.50, 0.75, 0.65)\rangle$
Moderate little	MEE	$\langle(0.40, 0.30, 0.35); (0.50, 0.45, 0.60); (0.45, 0.40, 0.60)\rangle$
Moderate	MOE	$\langle(0.50, 0.45, 0.50); (0.40, 0.35, 0.50); (0.35, 0.30, 0.45)\rangle$
Moderate high	HHH	$\langle(0.60, 0.45, 0.50); (0.20, 0.15, 0.25); (0.10, 0.25, 0.15)\rangle$
High	HIH	$\langle(0.70, 0.75, 0.80); (0.15, 0.15, 0.25); (0.10, 0.15, 0.15)\rangle$
Exceedingly high	ELG	$\langle(0.95, 0.90, 0.95); (0.10, 0.10, 0.05); (0.05, 0.05, 0.05)\rangle$

Step 3. Construct a decision matrix of main dimensions or their sub-indicators by consultants to show their preferences to identify the main dimensions and their sub-indicators weights using the linguistic terms, then by using T2NNs.
Step 4. Calculate the score function for the T2NN valuations according to Eq. (1)[18].

$$S(\tilde{Z}_{ij}) = \frac{1}{12}\left\langle 8 + \left(T_{T_{\tilde{Z}_{ij}}}(a) + 2\left(T_{I_{\tilde{Z}_{ij}}}(a)\right) + T_{F_{\tilde{Z}_{ij}}}(a)\right) - \left(I_{T_{\tilde{Z}_{ij}}}(a) + 2\left(I_{I_{\tilde{Z}_{ij}}}(a)\right) + I_{F_{\tilde{Z}_{ij}}}(a)\right) - \left(F_{T_{\tilde{Z}_{ij}}}(a) + 2\left(F_{I_{\tilde{Z}_{ij}}}(a)\right) + F_{F_{\tilde{Z}_{ij}}}(a)\right)\right\rangle, \; i = 1, \dots, m; \; j = 1, \dots, n. \tag{1}$$

Step 5. Determine the local weights for the main dimensions and their sub-indicators based on the opinions of the consultants. In this regard, the global weights of the sub-indicators are determined, which are used in evaluating and arranging the selected alternatives.
Step 6. Building a decision matrix between the selected alternatives and sub-indicators according to the opinions of consultants to express their preferences for these alternatives using linguistic terms, then using the T2NNs in Table 2.
Step 7. Convert the T2NNs to real values using Eq. (1).
Step 8. Calculate the normalized decision matrix according to Eq. (2) for benefit indicators *B*, and for cost indicators *C*.

$$y_{ij} = \begin{cases} \dfrac{y_{ij}}{\max_i y_{ij}} & if \;\; j \in B \\ \dfrac{\min_i y_{ij}}{y_{ij}} & if \;\; j \in C \end{cases}$$
(2)

Step 9. Compute the weighted normalized decision matrix according to Eq. (3). Here $(w_j)_{1\times n}$ introduces weight of j^{th} indicator.

$$G = \left[g_{ij}\right]_{n\times m} = w_j \times y_{ij} \quad (3)$$

Step 10. Identify the negative ideal solution NS_j for each indicator according to Eq. (4).

$$NS = \left[ns_j\right]_{1\times m} = \min_i g_{ij} \quad (4)$$

Step 11. Compute the Euclidean and Taxicab distances of substitutes from negative ideal solution by employing the Eqs. (5) and (6).

$$E_i = \sqrt{\sum_{j=1}^{n}\left(g_{ij} - NS_j\right)^2} \quad (5)$$

$$T_i = \sum_{j=1}^{n}\left|g_{ij} - NS_j\right| \quad (6)$$

Step 12. Construct the comparative valuation matrix $[h_{is}]_{n\times n}$ according to Eq. (7).

$$h_{is} = (E_i - E_s) + (\gamma(E_i - E_s) \times (T_i - T_s)) \quad (7)$$

where $s \in \{1, 2\ldots m\}$ and γ designates a threshold function to identify the equality of the Euclidean distances of two substitutes.

Step 13. Compute the valuation score of each substitute according to Eq. (8). Rank the substitutes according to the greatest valuation score is the one that is measured to be the optimum substitute.

$$F_i = \sum_{k=1}^{n} h_{is} \quad (8)$$

3. Application

In this section, the steps of the proposed methodology T2NN-CODAS are applied to evaluate and determine the most appropriate scenarios for the development of intelligent reverse logistics services. This section is divided into three parts. The first part is about identifying experts, main dimensions, and their sub-indicators. In addition, the alternatives selected for the study are defined. In the second part, the steps of the proposed methodology are applied. The third part discusses and analyzes the results of the study.

Step 1. The problem was studied and the main objective was determined, which is to choose the most appropriate scenario among the scenarios for developing smart reverse logistics services. Also, four consultants were identified for the participation of the authors in conducting the study and evaluating the four main dimensions and their eight sub-indicators that have an impact on choosing the most appropriate scenario for the development of reverse logistics services.

Step 2. Seven terms and their corresponding T2NNs were identified, as shown in Table 2, for use by the participants in the assessment process, whether for the main dimensions and their sub-indicators or the selected alternatives.

Step 3. The evaluation dimensions and their sub-indicators have been identified. The four evaluation dimensions that have been identified are economic (D_1), technical (D_2), environmental (D_3), and service quality (D_4). In addition, each main dimension includes two sub-indicators. The eight sub-indicators in a row are investment and logistics costs (D_{1_1}), conservation of property value (D_{1_1}), developmental level (D_{2_1}), complexity and compatibility (D_{2_2}), waste and emissions reduction (D_{3_1}), protection of energy sources (D_{3_2}), reliability and flexibility (D_{4_1}), and time efficiency (D_{4_2}). In addition, the selected alternatives are four scenarios. The four scenarios are defined as follows:

- *Scenario 1 (A_1)*
  The Internet of Things, cloud computing, and electronic and mobile markets are the three technologies that are most suited to Industry 4.0, and the first scenario assumes that they will be used to accomplish some of the fundamental tasks.
- *Scenario 2 (A_2)*
  The second scenario contains the technologies and their applications from the first scenario, as well as some more applications of the same technologies, as well as the applications of autonomous vehicles, artificial intelligence, big data, and data mining in reverse logistics

networks. In addition, this scenario also includes some further applications of the same technologies.

- *Scenario 3 (A_3)*
  This scenario encompasses the technologies utilized in previous instances, while also incorporating supplementary ones. Another potential application of the Internet of Things is the implementation of a control system, which involves a shift from traditional pushed flows to pulled flows. The system offers data regarding the timing, geographical coordinates, and quantity of waste that necessitates collection, thereby streamlining waste management within an extensive physical region encompassed by the reverse logistics network.
- *Scenario 4 (A_4)*
  This scenario represents the highest level of complexity, involving the integration of all relevant Industry 4.0 technologies and their established or potential uses within the reverse logistics network. In this scenario, the utilization of IoT technology is extended to encompass the development of a comprehensive reverse logistics information management system. The primary objective of this system is to gather precise and dependable real-time data regarding the evolving characteristics of products. The system facilitates the monitoring, gathering, and administration of data, as well as the decision-making process pertaining to the handling of reverse flow materials and products and the utilization of resources.

Step 4. A decision matrix of main dimensions was created by the four consultants to show their preferences of the main dimensions weights using the linguistic terms as presented in Table 3, then by using T2NNs as exhibited in Table 4. The final weights of the main dimensions are presented in Table 4 and shown in Figure 2.

Table 3. Assessment matrix of main dimensions by the four consultants using semantic terms.

Consultants	Criteria			
	D_1	D_2	D_3	D_4
Consultant_1	ELG	LLE	HHH	ELE
Consultant_2	MEE	MEE	HIH	HIH
Consultant_3	MOE	HIH	ELG	MOE
Consultant_4	HIH	HHH	MOE	HHH

Table 4. Assessment matrix of main dimensions by the four consultants using T2NNs.

Consultants	Main dimensions	
	D_1	D_2
Consultant_1	$\langle(0.95, 0.90, 0.95); (0.10, 0.10, 0.05); (0.05, 0.05, 0.05)\rangle$	$\langle(0.35, 0.35, 0.10); (0.50, 0.75, 0.80); (0.50, 0.75, 0.65)\rangle$
Consultant_2	$\langle(0.40, 0.30, 0.35); (0.50, 0.45, 0.60); (0.45, 0.40, 0.60)\rangle$	$\langle(0.40, 0.30, 0.35); (0.50, 0.45, 0.60); (0.45, 0.40, 0.60)\rangle$
Consultant_3	$\langle(0.50, 0.45, 0.50); (0.40, 0.35, 0.50); (0.35, 0.30, 0.45)\rangle$	$\langle(0.70, 0.75, 0.80); (0.15, 0.15, 0.25); (0.10, 0.15, 0.15)\rangle$
Consultant_4	$\langle(0.70, 0.75, 0.80); (0.15, 0.15, 0.25); (0.10, 0.15, 0.15)\rangle$	$\langle(0.60, 0.45, 0.50); (0.20, 0.15, 0.25); (0.10, 0.25, 0.15)\rangle$
Weight	0.266	0.219
Consultants	D_3	D_4
Consultant_1	$\langle(0.60, 0.45, 0.50); (0.20, 0.15, 0.25); (0.10, 0.25, 0.15)\rangle$	$\langle(0.20, 0.20, 0.10); (0.65, 0.80, 0.85); (0.45, 0.80, 0.70)\rangle$
Consultant_2	$\langle(0.70, 0.75, 0.80); (0.15, 0.15, 0.25); (0.10, 0.15, 0.15)\rangle$	$\langle(0.70, 0.75, 0.80); (0.15, 0.15, 0.25); (0.10, 0.15, 0.15)\rangle$
Consultant_3	$\langle(0.95, 0.90, 0.95); (0.10, 0.10, 0.05); (0.05, 0.05, 0.05)\rangle$	$\langle(0.50, 0.45, 0.50); (0.40, 0.35, 0.50); (0.35, 0.30, 0.45)\rangle$
Consultant_4	$\langle(0.50, 0.45, 0.50); (0.40, 0.35, 0.50); (0.35, 0.30, 0.45)\rangle$	$\langle(0.60, 0.45, 0.50); (0.20, 0.15, 0.25); (0.10, 0.25, 0.15)\rangle$
Weight	0.290	0.224

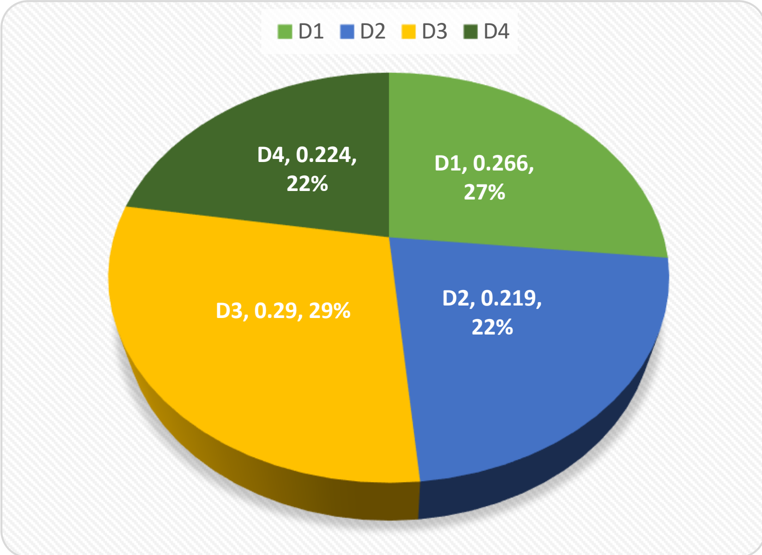

Figure 2. Weights of main dimensions.

Step 5. A decision matrix of all sub-indicators was created by the four consultants to show their preferences of the sub-indicators weights using the linguistic terms as presented in Table 5, then by using T2NNs as exhibited in Table 6. The final weights of all sub-indicators are presented in Tables 6-9. Also, the global weights of the sub-indicators were calculated based on the weights of the main dimensions and the weights of the local sub-indicators as presented in Table 10 and shown in Figure 3.

Table 5. Assessment matrix of all sub-indicators using semantic terms.

Consultants	All sub-indicators							
	D_{1_1}	D_{1_2}	D_{2_1}	D_{2_2}	D_{3_1}	D_{3_2}	D_{4_1}	D_{4_2}
Consultant_1	ELG	LLE	HHH	ELE	HHH	ELG	HIH	ELE
Consultant_2	MEE	MEE	HIH	HIH	HIH	MEE	MEE	LLE
Consultant_3	MOE	HIH	ELG	MOE	ELE	MOE	MOE	HHH
Consultant_4	HIH	HHH	MOE	HHH	LLE	ELG	MEE	HIH

Table 6. Assessment matrix of economic dimension's sub-indicators using T2NNs.

Consultants	Economic dimension's sub-indicators	
	D_{1_1}	D_{1_2}
Consultant_1	$\langle(0.95, 0.90, 0.95); (0.10, 0.10, 0.05); (0.05, 0.05, 0.05)\rangle$	$\langle(0.35, 0.35, 0.10); (0.50, 0.75, 0.80); (0.50, 0.75, 0.65)\rangle$
Consultant_2	$\langle(0.40, 0.30, 0.35); (0.50, 0.45, 0.60); (0.45, 0.40, 0.60)\rangle$	$\langle(0.40, 0.30, 0.35); (0.50, 0.45, 0.60); (0.45, 0.40, 0.60)\rangle$
Consultant_3	$\langle(0.50, 0.45, 0.50); (0.40, 0.35, 0.50); (0.35, 0.30, 0.45)\rangle$	$\langle(0.70, 0.75, 0.80); (0.15, 0.15, 0.25); (0.10, 0.15, 0.15)\rangle$
Consultant_4	$\langle(0.70, 0.75, 0.80); (0.15, 0.15, 0.25); (0.10, 0.15, 0.15)\rangle$	$\langle(0.60, 0.45, 0.50); (0.20, 0.15, 0.25); (0.10, 0.25, 0.15)\rangle$
Weight	0.548	0.452

Table 7. Assessment matrix of technical dimension's sub-indicators using T2NNs.

Consultants	Technical dimension's sub-indicators	
	D_{2_1}	D_{2_2}
Consultant_1	$\langle(0.60, 0.45, 0.50); (0.20, 0.15, 0.25); (0.10, 0.25, 0.15)\rangle$	$\langle(0.20, 0.20, 0.10); (0.65, 0.80, 0.85); (0.45, 0.80, 0.70)\rangle$
Consultant_2	$\langle(0.70, 0.75, 0.80); (0.15, 0.15, 0.25); (0.10, 0.15, 0.15)\rangle$	$\langle(0.70, 0.75, 0.80); (0.15, 0.15, 0.25); (0.10, 0.15, 0.15)\rangle$
Consultant_3	$\langle(0.95, 0.90, 0.95); (0.10, 0.10, 0.05); (0.05, 0.05, 0.05)\rangle$	$\langle(0.50, 0.45, 0.50); (0.40, 0.35, 0.50); (0.35, 0.30, 0.45)\rangle$
Consultant_4	$\langle(0.50, 0.45, 0.50); (0.40, 0.35, 0.50); (0.35, 0.30, 0.45)\rangle$	$\langle(0.60, 0.45, 0.50); (0.20, 0.15, 0.25); (0.10, 0.25, 0.15)\rangle$

Weight	0.564	0.436

Table 8. Assessment matrix of environmental dimension's sub-indicators using T2NNs.

Consultants	Environmental dimension's sub-indicators	
	D_{3_1}	D_{3_2}
$Consultant_1$	⟨(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)⟩
$Consultant_2$	⟨(0.70, 0.75, 0.80); (0.15, 0.15, 0.25); (0.10, 0.15, 0.15)⟩	⟨(0.40, 0.30, 0.35); (0.50, 0.45, 0.60); (0.45, 0.40, 0.60)⟩
$Consultant_3$	⟨(0.20, 0.20, 0.10); (0.65, 0.80, 0.85); (0.45, 0.80, 0.70)⟩	⟨(0.50, 0.45, 0.50); (0.40, 0.35, 0.50); (0.35, 0.30, 0.45)⟩
$Consultant_4$	⟨(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)⟩
Weight	0.416	0.584

Table 9. Assessment matrix of service quality dimension's sub-indicators using T2NNs.

Consultants	Service quality dimension's sub-indicators	
	D_{4_1}	D_{4_2}
$Consultant_1$	⟨(0.70, 0.75, 0.80); (0.15, 0.15, 0.25); (0.10, 0.15, 0.15)⟩	⟨(0.20, 0.20, 0.10); (0.65, 0.80, 0.85); (0.45, 0.80, 0.70)⟩
$Consultant_2$	⟨(0.40, 0.30, 0.35); (0.50, 0.45, 0.60); (0.45, 0.40, 0.60)⟩	⟨(0.35, 0.35, 0.10); (0.50, 0.75, 0.80); (0.50, 0.75, 0.65)⟩
$Consultant_3$	⟨(0.50, 0.45, 0.50); (0.40, 0.35, 0.50); (0.35, 0.30, 0.45)⟩	⟨(0.60, 0.45, 0.50); (0.20, 0.15, 0.25); (0.10, 0.25, 0.15)⟩
$Consultant_4$	⟨(0.40, 0.30, 0.35); (0.50, 0.45, 0.60); (0.45, 0.40, 0.60)⟩	⟨(0.70, 0.75, 0.80); (0.15, 0.15, 0.25); (0.10, 0.15, 0.15)⟩
Weight	0.527	0.473

Table 10. Final global weights of main dimensions and their sub-indicators.

Main dimensions	Weights of dimensions	Sub-indicators	Global weight of sub-indicators
Economic D_1	0.266	Investment and logistics costs D_{1_1}	0.146
		Conservation of property value D_{1_2}	0.120
Technical D_2	0.219	Developmental level D_{2_1}	0.124
		Complexity and compatibility D_{2_2}	0.095
Environmental D_3	0.290	Waste and emissions reduction D_{3_1}	0.121
		Protection of energy sources D_{3_2}	0.169
Service quality D_4	0.224	Reliability and flexibility D_{4_1}	0.118
		Time efficiency TPB_{4_2}	0.106

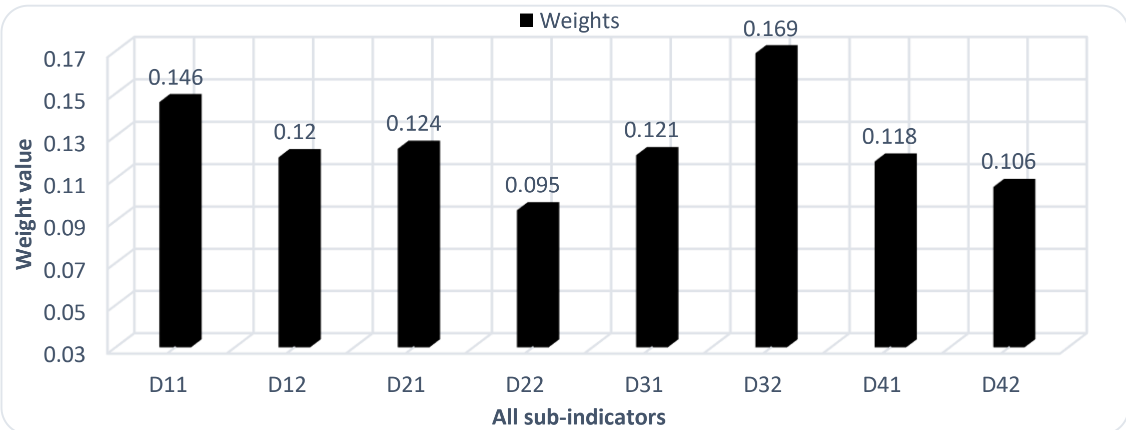

Figure 3. Final global weights of all sub-barriers.

Step 6. A decision matrix between the selected four scenarios and the eight sub-indicators was created according to the opinions of consultants to express their preferences for these scenarios using linguistic terms as exhibited in Table 11. The T2NNs was converted to real values according to Eq. (1).
Step 7. The normalized decision matrix was computed according to Eq. (2) for all sub-indicators as benefit indicators as presented in Table 12.
Step 8. The weighted normalized decision matrix was calculated according to Eq. (3), as presented in Table 13.
Step 9. The negative ideal solution was determined for each indicator according to Eq. (4), as displayed in Table 13.
Step 10. The Euclidean and Taxicab distances of substitutes from negative ideal solution were identified by employing the Eqs. (5) and (6), as presented in Table 14.
Step 11. The comparative valuation matrix was computed according to Eq. (7), as presented in Table 15. The four scenarios were ranked according to Eq. (8) as displayed in Table 15 and shown in Figure 4.

Table 11. Assessment matrix of the four scenarios according to the eight indicators using semantic terms.

Scenarios	All sub-indicators							
	D_{1_1}	D_{1_2}	D_{2_1}	D_{2_2}	D_{3_1}	D_{3_2}	D_{4_1}	D_{4_2}
Scenario_1	MOE	LLE	HHH	ELE	HHH	HHH	HIH	MOE
Scenario_2	MEE	ELE	HIH	ELG	MOE	MEE	MEE	LLE
Scenario_3	MOE	HIH	ELG	MOE	ELE	MOE	MOE	HIH
Scenario_4	HIH	MEE	MOE	HHH	LLE	ELG	MEE	HIH

Table 12. Normalized matrix of the four scenarios according to the eight indicators.

Scenarios	All sub-indicators							
	D_{1_1}	D_{1_2}	D_{2_1}	D_{2_2}	D_{3_1}	D_{3_2}	D_{4_1}	D_{4_2}
Scenario_1	0.716	0.383	0.763	0.258	1.000	0.763	1.000	0.716
Scenario_2	0.568	0.296	0.871	1.000	0.817	0.495	0.568	0.383
Scenario_3	0.716	1.000	1.000	0.624	0.338	0.624	0.716	1.000
Scenario_4	1.000	0.568	0.624	0.763	0.437	1.000	0.568	1.000

Table 13. Weighted normalized matrix of the four scenarios according to the eight indicators.

Scenarios	All sub-indicators							
	D_{1_1}	D_{1_2}	D_{2_1}	D_{2_2}	D_{3_1}	D_{3_2}	D_{4_1}	D_{4_2}
Scenario_1	0.105	0.046	0.095	0.025	0.121	0.129	0.118	0.076
Scenario_2	0.083	0.036	0.108	0.095	0.099	0.084	0.067	0.041
Scenario_3	0.105	0.120	0.124	0.059	0.041	0.105	0.084	0.106
Scenario_4	0.146	0.068	0.077	0.073	0.053	0.169	0.067	0.106
Negative ideal	0.083	0.036	0.077	0.025	0.041	0.084	0.067	0.041

Table 14. Euclidean and taxicab distances of the four scenarios.

Alternatives	E_i	T_i
Scenario_1	0.115	0.261

$Scenario_2$	0.096	0.159
$Scenario_3$	0.127	0.292
$Scenario_4$	0.138	0.306

Table 15. Comparative valuation matrix and ranking of the four scenarios.

Alternatives	$Scenario_1$	$Scenario_2$	$Scenario_3$	$Scenario_4$	F_i	Rank
$Scenario_1$	0.000	0.019	-0.012	-0.023	-0.016	3
$Scenario_2$	-0.018	0.000	-0.030	-0.041	-0.088	4
$Scenario_3$	0.012	0.031	0.000	-0.011	0.032	2
$Scenario_4$	0.023	0.043	0.011	0.000	0.078	1

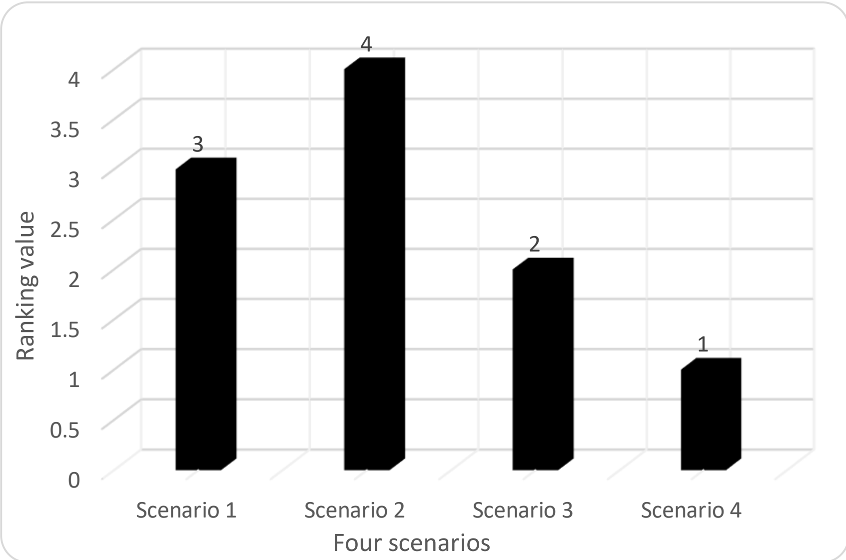

Figure 4. Final ranking of the four intelligent development logistics systems.

3.1 Results and discussion

In this part, the results obtained from the application of the proposed model to evaluate and determine the most suitable intelligent logistics development scenarios are discussed. The results are divided into two parts. The first part is concerned with evaluating the four main dimensions and their eight sub-indicators and determining the weights. The four main dimensions were evaluated through expert opinions as shown in Table 4.

The results indicate that the environmental dimension (D_3), is the dimension with the highest weight by 0.290, followed by the economic dimension (D_1) with a weight of 0.266, while the technical dimension (D_2) has the least weight by 0.219.

The second part is concerned with evaluating the four scenarios selected in the study. The four selected scenarios were arranged as shown in Table 15 and Figure 4. The results show that Scenario 4 (A_4) is the highest in the order, followed by Scenario 3 (A_3), while Scenario 2 (A_2) is the lowest in the order.

4. Conclusions

The primary objective of this study was to ascertain the framework for the advancement of smart reverse logistics, which can guide decision-making at both strategic and tactical levels. Additionally, the study aimed to develop a reverse logistics system that is universally accepted by all key stakeholders, thereby facilitating its extensive implementation and maximizing the associated positive outcomes. In light of this consideration, the study formulated four development scenarios. The individuals were assessed based on four dimensions that considered the objectives and concerns of the primary stakeholders. A proposed solution to address the defined problem involves the utilization of a T2NN-CODAS MCDM method. The formulation of the complete smart reverse logistics development scenarios as well as the framework for their assessment and ranking is the primary addition that this research makes to the existing body of literature dealing with reverse logistics and Industry 4.0.

Data availability

The datasets generated during and/or analyzed during the current study are not publicly available due to the privacy-preserving nature of the data but are available from the corresponding author upon reasonable request.

Conflict of interest

The authors declare that there is no conflict of interest in the research.

Ethical approval

This article does not contain any studies with human participants or animals performed by any of the authors.

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