Decision Support Model with TreeSoft Set for Assessment of Coupled and Coordinated Development of Digital Transportation Technology and Industry

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Abstract: The integration of digital transportation technology and the transportation industry has become a crucial factor in shaping modern mobility systems, enhancing operational efficiency, and promoting sustainability. This study evaluates the coupled and coordinated development of digital transportation innovations. Using multi-criteria decision-making (MCDM) methodologies, this research assesses key factors using BWM to compute the criteria weights. The MOOSRA method is used to rank the alternatives. This study uses the TreeSoft set to divide the criteria and sub criteria as set of levels and in each level, we compute the criteria weights. A case study with five criteria and different sub criteria with seven alternatives is conducted in this study. We conducted sensitivity analysis by using different criteria weights. This evaluation provides a systematic framework for decision-makers to optimize digital transportation strategies, ensuring a harmonized, resilient, and future-ready transportation ecosystem.

Keywords: TreeSoft Set; Decision Support Model; Coupled and Coordinated; Digital Transportation Technology and Industry.

1. Introduction

The rapid advancement of digital transportation technology is transforming the global transportation industry, leading to smarter, more efficient, and sustainable mobility solutions. The integration of artificial intelligence (AI), the Internet of Things (IoT), big data analytics, blockchain, and cloud computing has significantly improved traffic management, logistics optimization, and passenger convenience. However, the successful adoption of these digital innovations depends on the coordinated development between technology and the transportation industry, ensuring that infrastructure, policies, and operational frameworks align with technological progress. As digitalization reshapes transportation networks, evaluating the level of integration and coordination between these two sectors is crucial for enhancing system efficiency, reducing costs, and maximizing societal benefits[1], [2].

The coupling and coordination of digital technology and the transportation industry require a balanced approach that fosters innovation while addressing industry-specific challenges. While advanced technologies such as autonomous vehicles, intelligent traffic systems, and Mobility-as-a-Service (MaaS) platforms offer promising solutions, their effectiveness depends on industry readiness, government regulations, and financial investments. Some regions and sectors have rapidly adopted digital transportation solutions, while others face barriers such as infrastructure limitations, cybersecurity risks, and resistance to change. A well-structured evaluation framework can provide insights into how well these technologies are being integrated into different transportation models and help identify the gaps that hinder seamless collaboration between technology providers and transportation service operators[3], [3].

To assess the effectiveness of digital transportation technology in the industry, multi-criteria decision-making (MCDM) methodologies can be employed. These methods allow researchers and policymakers to evaluate key performance indicators such as technological integration, industry adaptability, investment in digital infrastructure, operational efficiency, and sustainability. By applying MCDM techniques, decision-makers can rank transportation models based on their digital readiness, economic feasibility, and societal impact. Such an approach ensures that digital transformation efforts align with broader industry goals, improving the overall quality and reliability of transportation systems while fostering environmental sustainability[4], [5].

Despite its advantages, the integration of digital technology into transportation is not without challenges. The unequal distribution of digital infrastructure, cybersecurity concerns, high initial investment costs, and workforce training remain critical obstacles. Additionally, the rate of technological change often outpaces industry adaptation, leading to gaps in policymaking and regulation. Therefore, evaluating the coupled and coordinated development of digital transportation technology and industry is not just about measuring technological progress but also about understanding the institutional, economic, and societal factors that influence adoption and scalability. Addressing these challenges requires collaboration between governments, private enterprises, and research institutions to develop scalable, adaptable, and future-proof digital transportation solutions.

A systematic evaluation of the relationship between digital transportation technology and industry will provide valuable insights for stakeholders looking to enhance efficiency, promote sustainable mobility, and future-proof transportation systems. As the world moves toward smart cities and intelligent transportation networks, it is essential to ensure that technological advancements are effectively integrated into existing infrastructure, regulations, and industry practices. By assessing the level of digital coordination and its impact on operational performance, policymakers and industry leaders can make informed decisions that lead to a more connected, resilient, and sustainable transportation ecosystem[6], [7].

This study proposed a decision support model for Evaluation of Coupled and Coordinated Development of Digital Transportation Technology and Industry using MCDM methods. The main contributions of this study are organized as follows:

Two MCDM methods are used in this study such as BWM to compute the criteria weights and the MOOSRA method to rank the alternatives.

TreeSoft Set is used to divide the criteria and sub criteria as levels and each level includes different nodes.

The case Study is provided to show the validation of the proposed decision support system by including five main criteria and seven alternatives.

Sensitivity analysis is conducted to show the stability of the ranks of the alternatives under different criteria weights.

2. Decision Support Model

The experiment is conducted for Evaluation of Coupled and Coordinated Development of Digital Transportation Technology and Industry. This study uses two MCDM methods for this evaluation such as BWM and MOOSRA. BWM is used to compute the criteria weights and the MOOSRA method is used to rank alternatives[8], [9], [10]. We use the TreeSoft Set to deal with criteria and sub criteria. The steps of the decision support model are organized as follows:

Step 1. Build a Tree and compute its nodes.

- Level 1: This level contains the main criteria; these criteria are represented as nodes. This study uses five main criteria, so we have five nodes in the first level.
- Level 2: This level is divided into different branches; each branch shows the sub criteria. Each node has different sub criteria, these sub criteria are presented as sub nodes[11], [12].

Let U be a universal set and H be a non-empty subset of U, the power set of H is $P(H)$. The set of criteria are $C_1, \dots, C_n; n \geq 2$. $C_1 \cap C_2 \cap \dots \cap C_n = \emptyset; F: P(C) \rightarrow P(H)$ is a MultiSoft set.

The TreeSoft Set can be defined as:

$$C_1 = \{C_{1,1}, C_{1,2}, \dots\}$$
$$C_2 = \{C_{2,1}, C_{2,2}, \dots\}$$
$$C_3 = \{C_{3,1}, C_{3,2}, \dots\}$$
$$\vdots$$
$$C_n = \{C_{n,1}, C_{n,2}, \dots\} \quad (1)$$

The TreeSoft set can be defined as a set of levels with the main level is root node[13], [14].

$$Tree(C) = \{C_{i_1}, i_1 = 1,2, \dots\} \cup \{C_{i_1,i_2}, i_1, i_2 = 1,2, \dots\} \cup \dots \cup \{C_{i_1,i_2,\dots i_m}, i_1, i_2, \dots . i_m = 1,2, \dots\}$$
(2)

Step 2. Computing the criteria weights.

In this step, we compute the criteria weights by the BWM. The steps of this method are organized as follows:

- Identification of the decision criteria. We define a set of criteria and sub criteria by the opinions of experts and literature reviews such as $C_1, \dots, C_n$.
- Define the best and worst criterion. Experts can define the best and worst criterion. We can present the best criterion as C_B and the worst criterion as C_W.
- Conduct comparison between the best criterion and other criteria. Experts can perform this step to show the best criterion over other criteria such as $C_B = (C_{B1}, \dots, C_{Bn})$.
- Conduct comparison between the worst criterion and other criteria. Experts can perform this step to show the worst criterion over other criteria such as $C_W = (C_{W1}, \dots, C_{Wn})^T$.
- Compute the optimal weights. The criteria weights can be computed as:
- $\min \max \left\{\left|w_B - C_{B_j} w_j\right|, \left|w_B - C_{W_j} w_W\right|\right\}$ subject to (3)
- $\sum_j w_j = 1$ (4)
- $w_j > 0;\ \forall_j$ (5)

Step 3. Ranking the alternatives.

In this step, we can obtain the rank of the alternatives by using the MOOSR method. The steps of this method are organized as follows:

- Build the decision matrix.
- $X = \begin{bmatrix} x_{11} & \cdots & x_{1n} \\ \vdots & \ddots & \vdots \\ x_{m1} & \cdots & x_{mn} \end{bmatrix}$ (6)
- Compute the normalized decision matrix.
- $h_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}}$ (7)
- Compute the weighted decision matrix.

- $u_{ij} = w_j h_{ij}$ (8)
- Compute the MOOSRA value as:
- $Q_{ij} = \frac{\sum_{j=1}^{g} u_{ij}}{\sum_{g+1}^{n} u_{ij}}$ (9)
- Rank the alternatives.

3. Results and Discussion

This section shows the results of the decision support model by providing the criteria weights and ranking of the alternatives. This study uses five criteria and different sub criteria with seven alternatives.

Step 1. We build a tree with two levels.

- Level 1: This level shows the five main criteria.
- Level 2: This level shows the sub criteria values. Fig 1 shows the Tree nodes of this study.

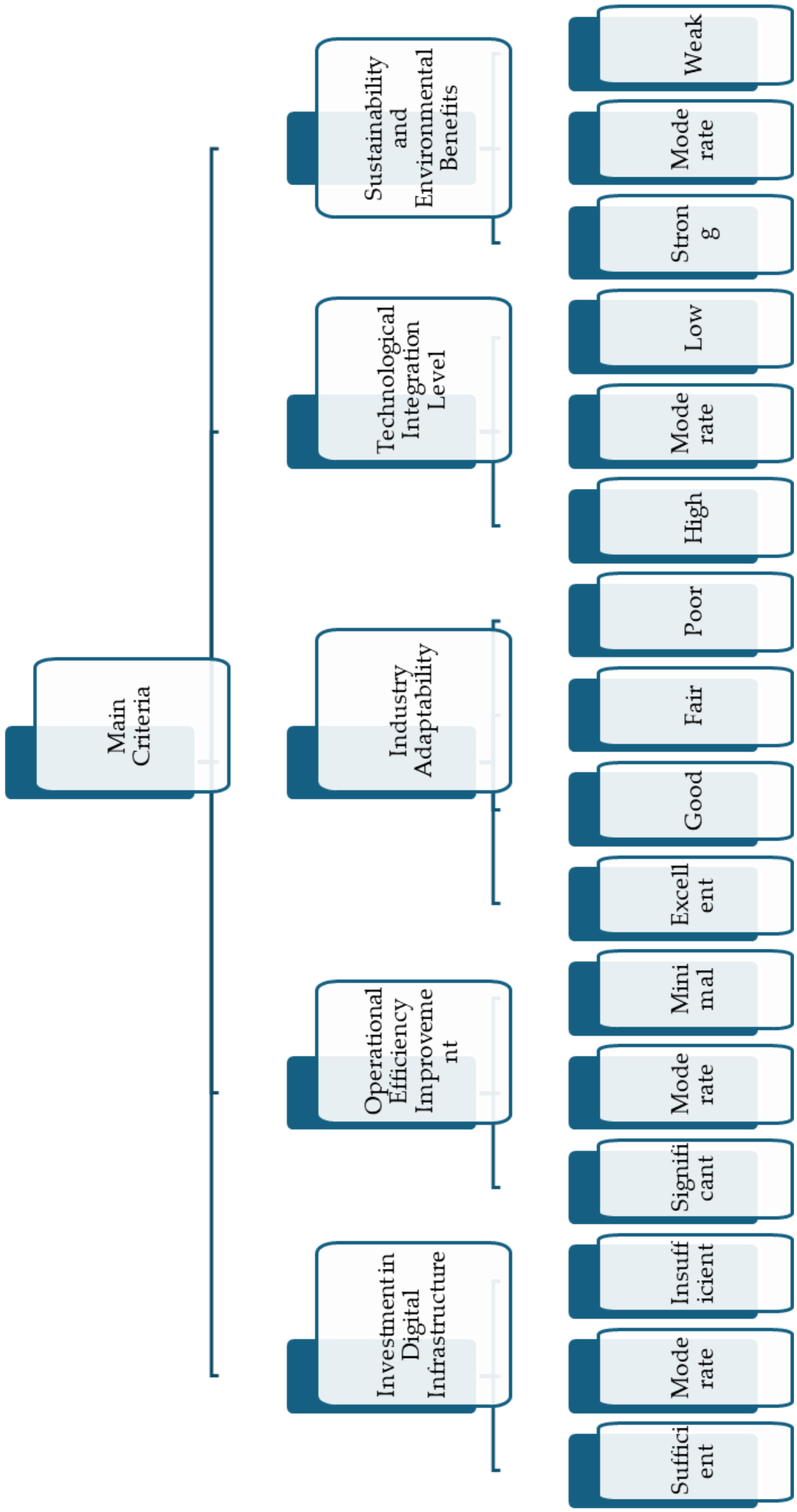
Main Criteria
Investment in Digital Infrastructure
Operational Efficiency Improvement
Industry Adaptability
Technological Integration Level
Sustainability and Environmental Benefits
Sufficient
Moderate
Insufficient
Significant
Moderate
Minimal
Excellent
Good
Fair
Poor
High
Moderate
Low
Strong
Moderate
Weak

Fig 1. Tree nodes of this study.

Step 2. We compute the criteria weights in each level. We compute the criteria weights in the main criteria and the sub criteria.

The results of the BWM are shown as:

- We define five main criteria and sub criteria as shown in Fig 1.
- Experts and decision makers are defined the best and worst criterion.
- We conducted the comparison between the best criterion over other criteria.
- We conducted the comparison between the worst criterion over other criteria.
- Then we obtain the criteria weights of the main criteria as shown in Fig 2.
- Then we apply the previous steps to compute the weights of the sub criteria as shown in Fig 3.

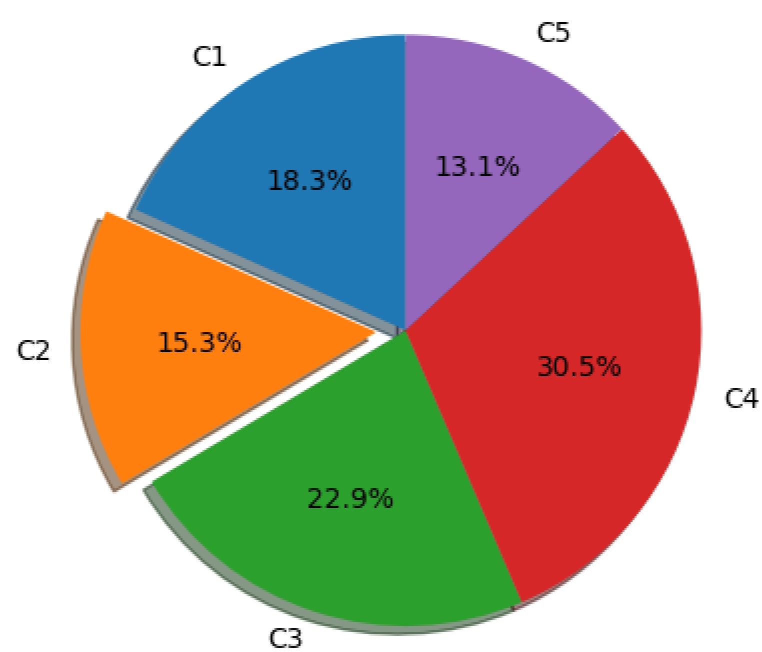

Fig 2. The weights of main criteria.

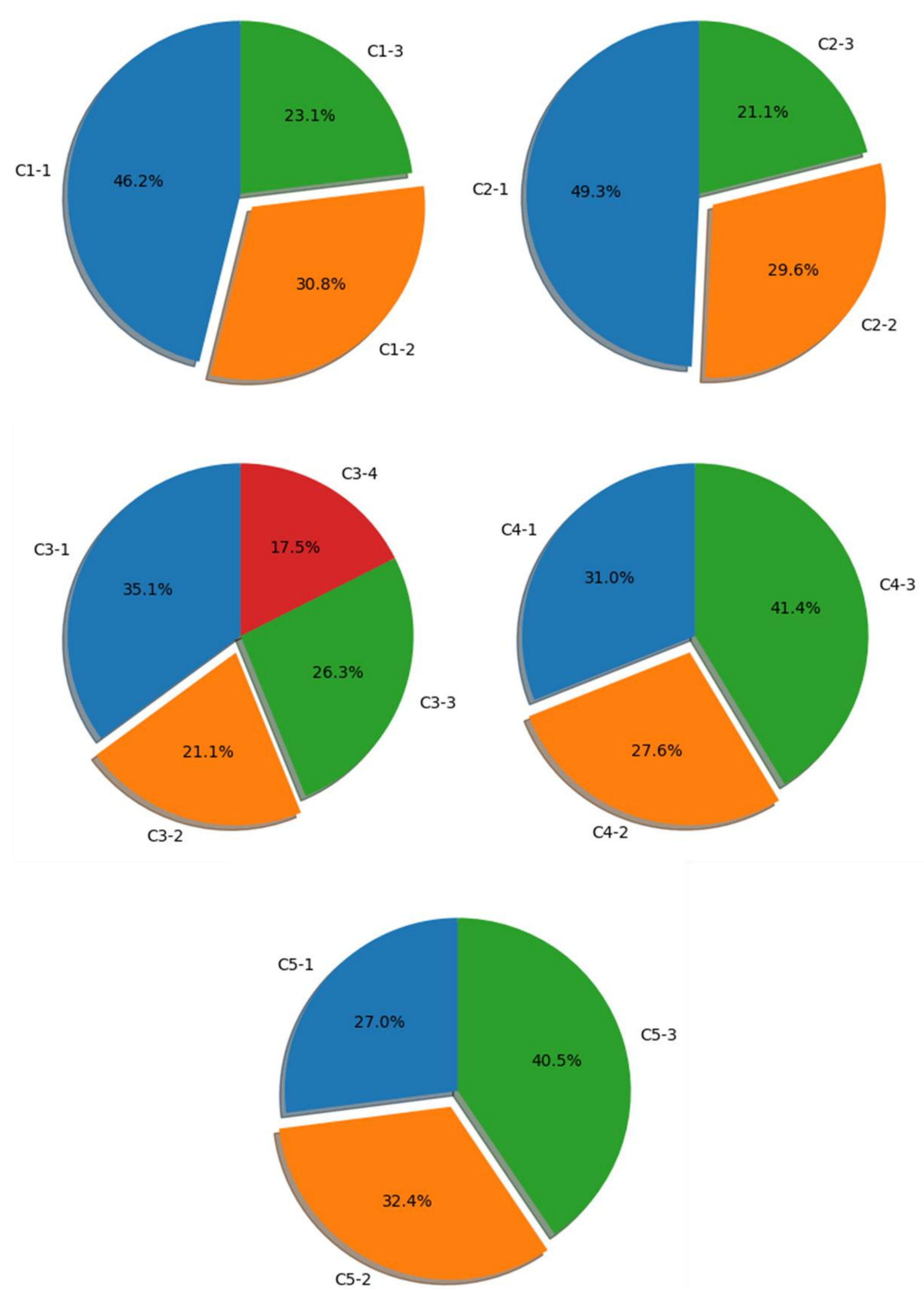

Fig 3. The weights of sub criteria.

Step 3. Ranking the alternatives.

We apply the steps of the MOOSRA method to rank the alternatives.

- We build the decision matrix using Eq. (1). Experts are used scale between 0.9 to 0.1 to evaluate the criteria and alternatives.
- We compute the normalized decision matrix using Eq. (7) as shown in Fig 4.
- Then we compute the weighted decision matrix using Eq. (8) as shown in Fig 5.
- Then we compute the MOOSRA value using Eq. (9) as shown in Fig 6.
- Then we rank the alternatives as shown in Fig 7.

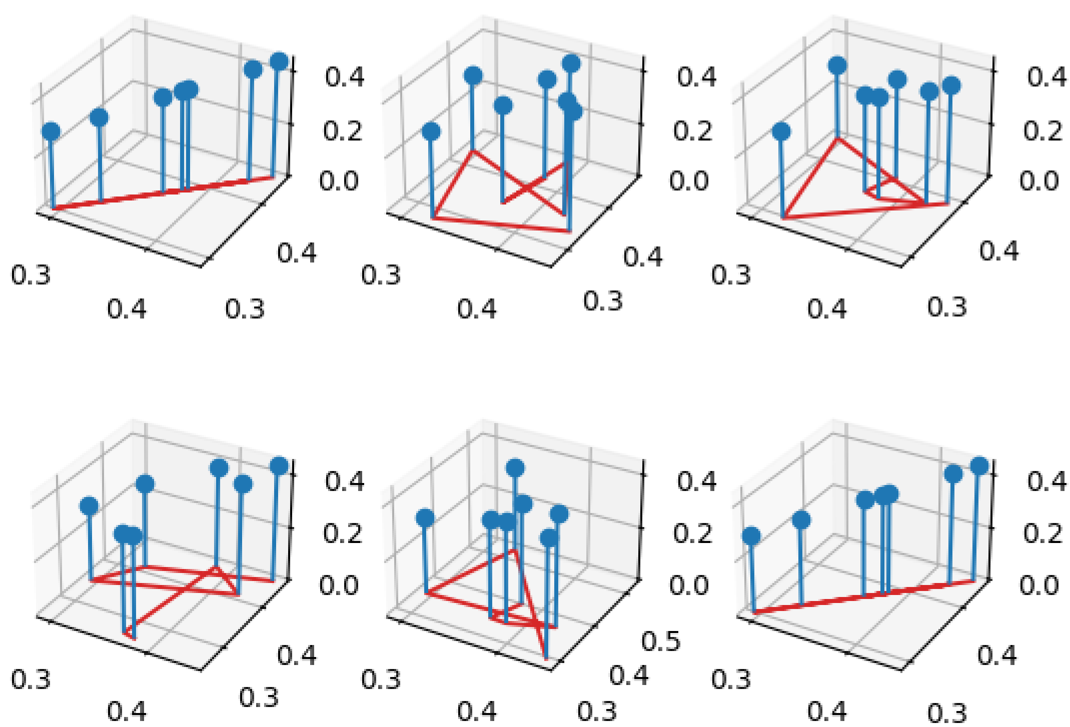

Fig 4. The normalized decision matrix.

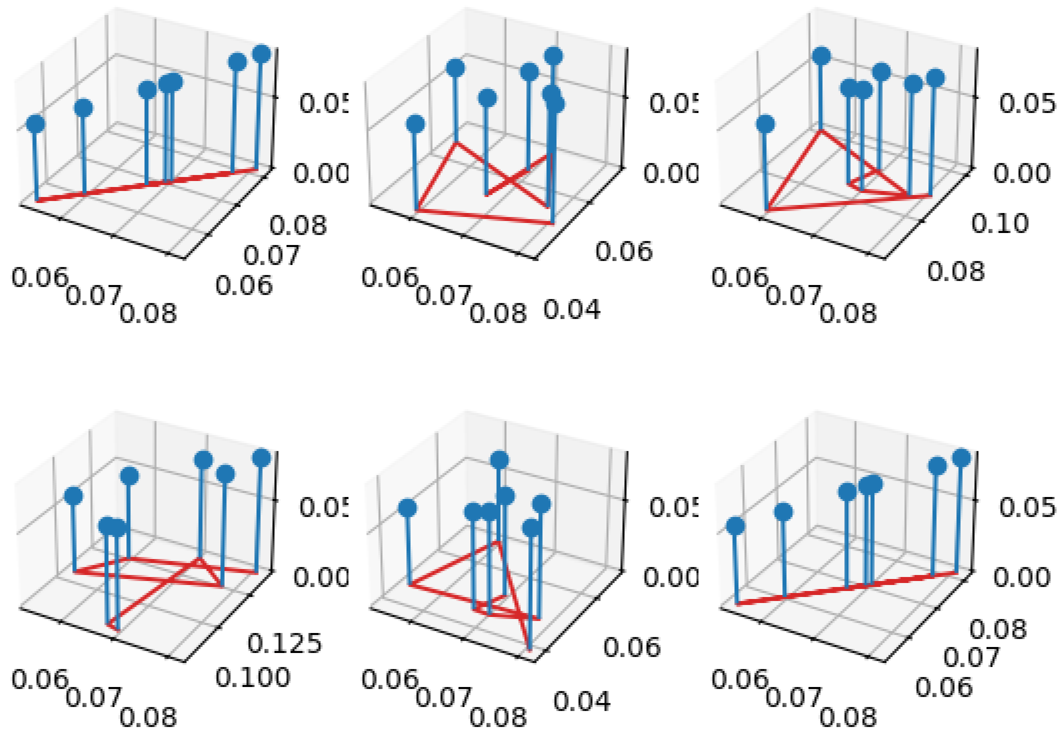

Fig 5. The weighted decision matrix.

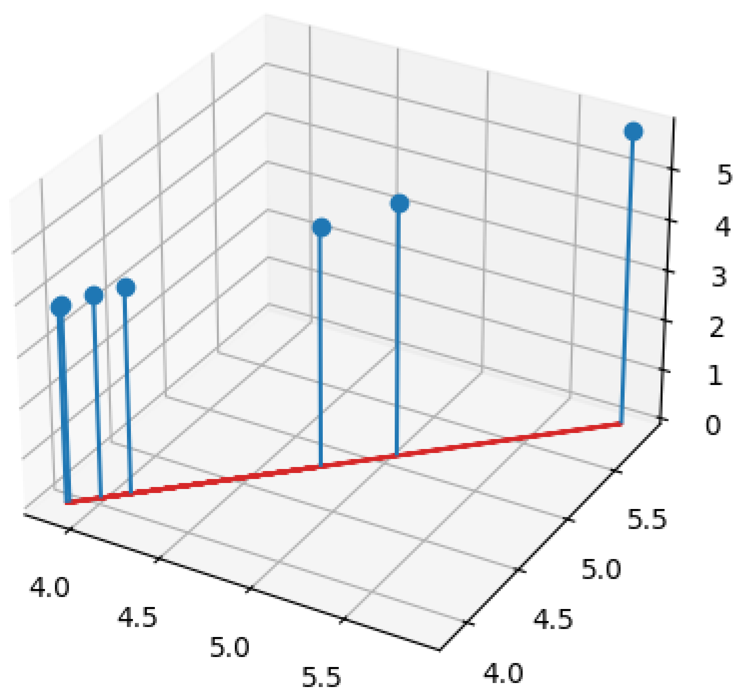

Fig 6. The MOOSRA value of each alternative.

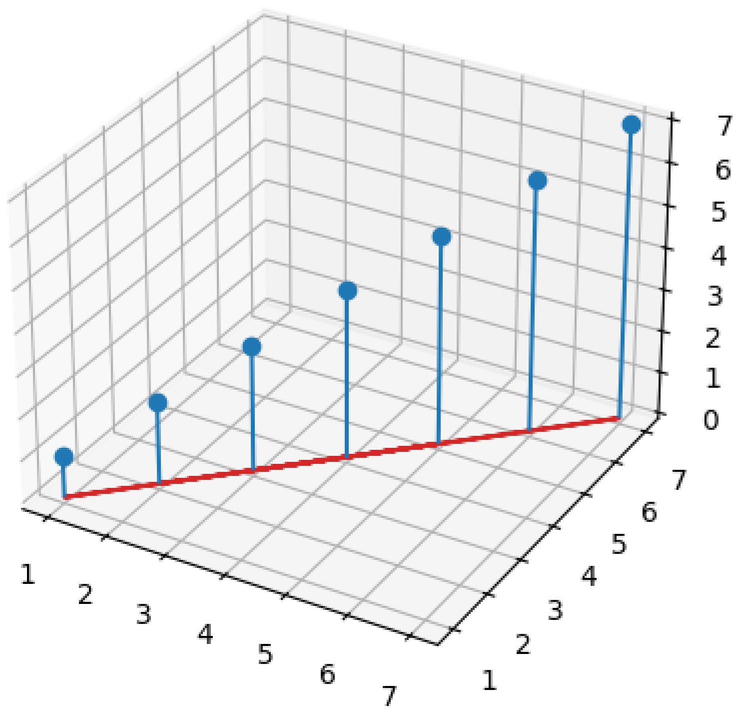

Fig 7. The rank of alternatives.

4. Analysis

This section conducted sensitivity analysis to show the rank of alternatives under different cases. This study proposes six cases in the criteria weights. We change the criteria weight, then we rank the alternatives. Fig 8 shows the different values of each criterion. In the first case, the criteria have the same weights. The second scale the first criterion weight is increased by 30% and other criteria have the same weights. The third scale the second criterion weight is increased by 30% and other criteria have the same weights. On the fourth scale the third criterion weight is increased by 30% and other criteria have the same weights.

The ranks of the alternatives are shown in Fig 9. We show the rank of alternatives in each case. The results show alternative 3 is the best and alternative 1 is the worst. We show the ranks of alternatives are stable under different cases. Fig 10. Shows the values of the MOOSRA score.

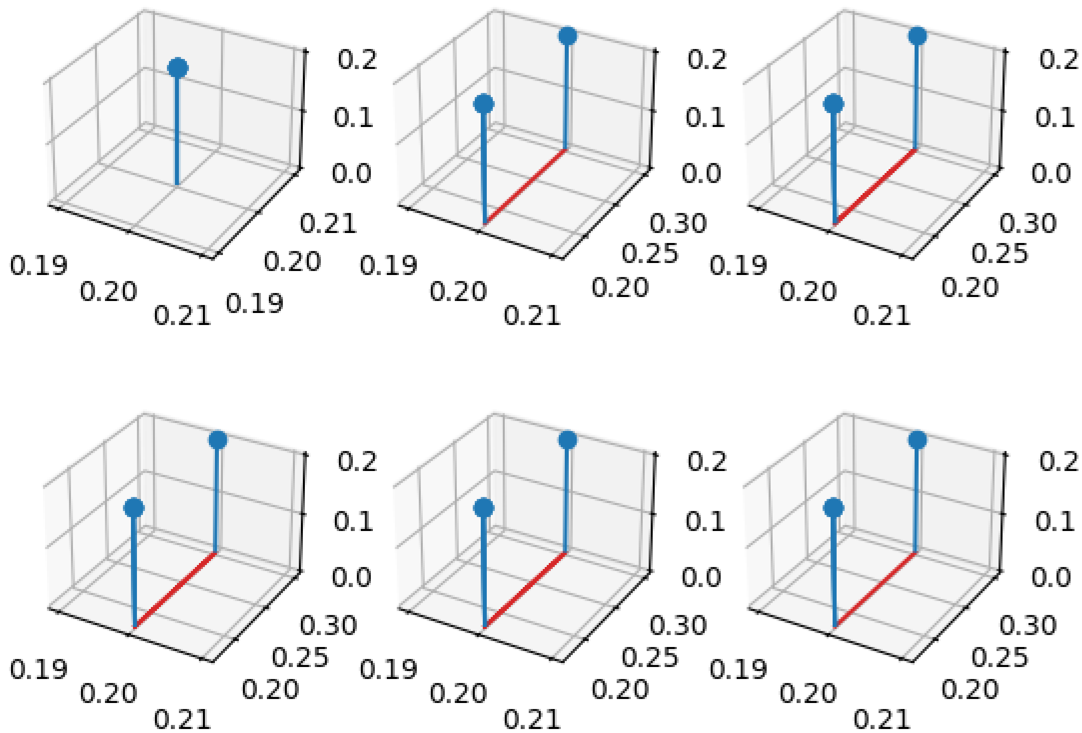

Fig 8. The different criteria weights.

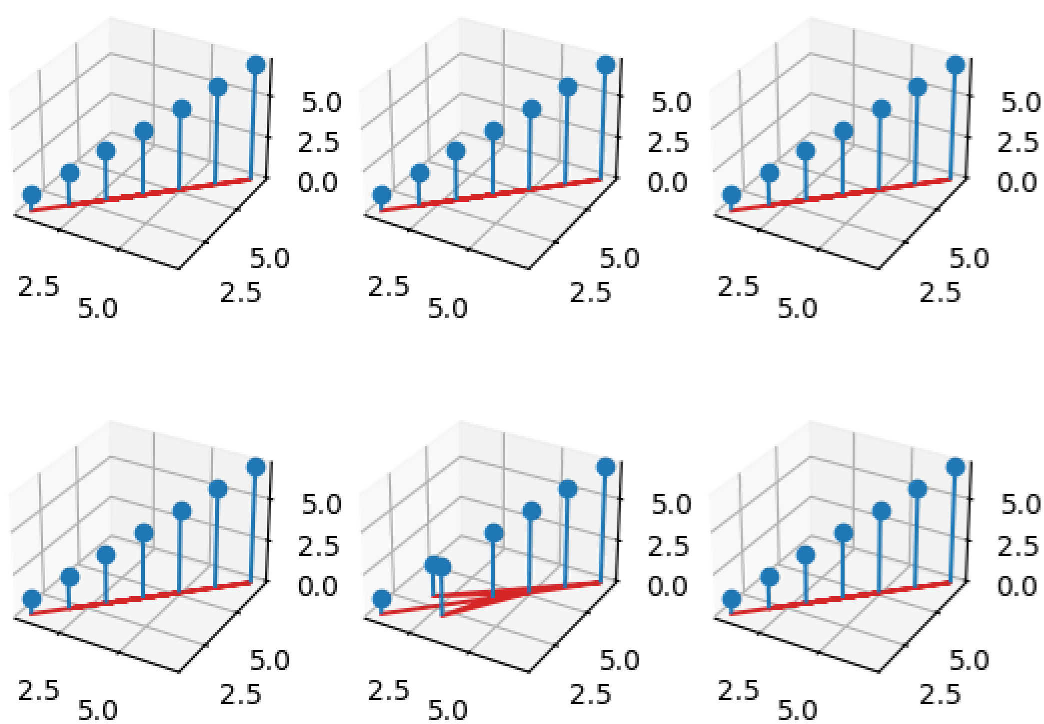

Fig 9. The different ranks of alternatives.

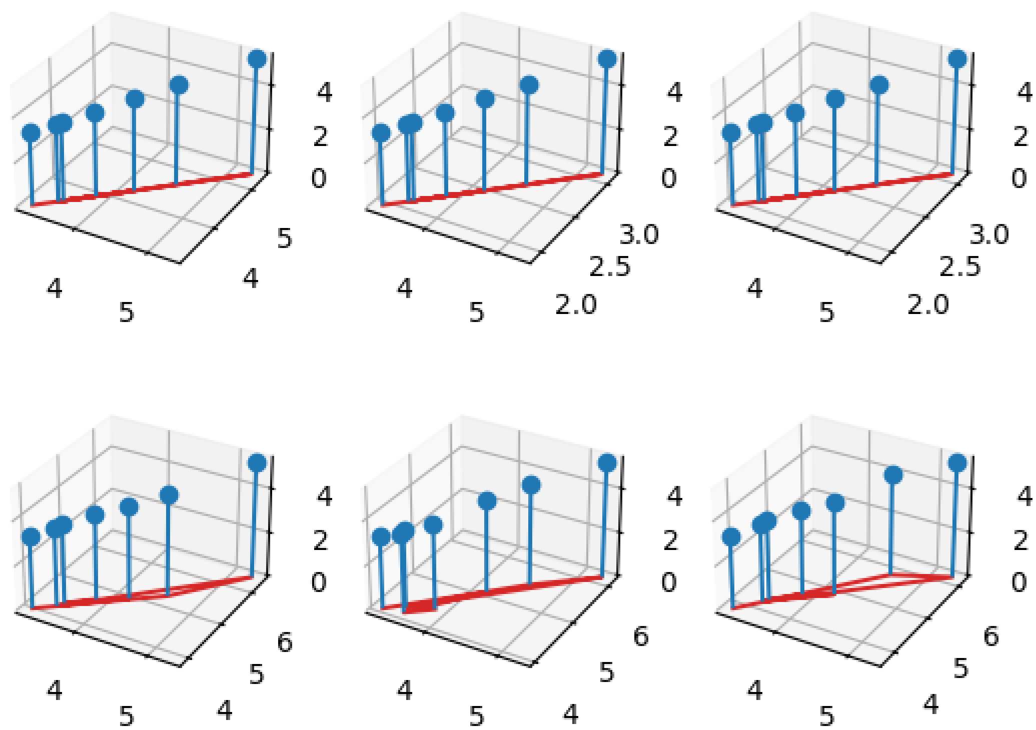

Fig 10. The different values of MOOSRA score.

5. Conclusions

The findings of this study underscore the importance of coupling and coordinating digital transportation technology with industry practices to enhance efficiency, reduce operational costs, and improve sustainability. While digital advancements such as AI-driven traffic management, autonomous vehicles, and Mobility-as-a-Service (MaaS) have shown significant potential, their effectiveness is highly dependent on industry adaptability, infrastructure readiness, and supportive policies. The research highlights the need for a structured evaluation framework, such as MCDM methodologies, to assess digital integration levels and guide decision-making in transportation development. We used two MCDM methods such as BWM to compute the criteria weights and the MOOSRA method to rank the alternatives. We used the TreeSoft set to deal with criteria and sub criteria.

Furthermore, the study reveals that disparities in digital adoption pose a major challenge, with some sectors rapidly advancing while others lag due to financial constraints, regulatory barriers, and technological gaps. Addressing these challenges requires collaborative efforts between governments, industry stakeholders, and technology providers to create scalable and adaptable digital transportation solutions. Investments in digital infrastructure, cybersecurity measures, and workforce training are essential to ensure a smooth transition toward smart mobility systems.

A key takeaway from this evaluation is the necessity of a long-term strategic approach that aligns technological innovation with industry needs. Without proper synchronization, digital transformation efforts may result in inefficiencies, fragmented systems, and missed opportunities for sustainable development. Therefore, a holistic, data-driven decision-making approach must be adopted to ensure the seamless integration of digital technology into transportation networks.

In conclusion, coordinated development between digital transportation technology and the transportation industry is a vital factor for achieving a smarter, more sustainable, and efficient mobility ecosystem. Policymakers and industry leaders must leverage systematic evaluation frameworks to identify strengths, weaknesses, and opportunities, ensuring that digital transformation in transportation leads to long-term economic, social, and environmental benefits.

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References

[1] Q. Song, S. Ji, and H. Deng, "Spatial–Temporal Evolution Characteristics and Influencing Factors for the Coupling Coordinated Development of Transport Logistics and Technology," *Sustainability*, vol. 17, no. 4, p. 1389, 2025.

[2] X. Ye, J. Wang, and R. Sun, "The coupling and coordination relationship of the digital economy and tourism industry from the perspective of industrial integration," *Eur. J. Innov. Manag.*, vol. 27, no. 4, pp. 1182–1205, 2024.

[3] N. Li, Y. Song, W. Xia, and S.-N. Fu, "Regional transportation integration and high-quality economic development, coupling coordination analysis, in the Yangtze River Delta, China," *Systems*, vol. 11, no. 6, p. 279, 2023.

[4] H. Shu, L. Zhan, X. Lin, and X. Zhou, "Coordination measure for coupling system of digital economy and rural logistics: An evidence from China," *PLoS One*, vol. 18, no. 4, p. e0281271, 2023.

[5] K. Yang, C.-P. Chang, Y. Ma, and G.-F. Feng, "Dynamic Coupling Coordination of Digital Economy and High-Quality Development in Transportation Sector," *Int. J. Transp. Econ. Riv. internazionale di Econ. dei Trasp. LI, 1/2, 2024*, pp. 157–191, 2024.

[6] Y. Guo and H. Ding, "Coupled and coordinated development of the data-driven logistics industry and digital economy: A case study of Anhui Province," *Processes*, vol. 10, no. 10, p. 2036, 2022.

[7] S. Zhou, J. Wang, and B. Xu, "Innovative coupling and coordination: Automobile and digital industries," *Technol. Forecast. Soc. Change*, vol. 176, p. 121497, 2022.

[8] V. R. R. Mota, C. F. S. Gomes, D. F. de Lima Silva, and M. dos Santos, "The novel hybrid multiple criteria decision method BWM-Moora-N applied for investment funds prioritization," *Oper. Res.*, vol. 24, no. 3, p. 36, 2024.

[9] S. Narayanamoorthy, V. Annapoorani, and D. Kang, "Assessment of E-waste site selection using MOOSRA based hesitant fuzzy multi-criteria decision making method," in *AIP Conference Proceedings*, AIP Publishing, 2020.

[10] F. Feizi, A. A. Karbalaei-Ramezanali, and S. Farhadi, "FUCOM-MOORA and FUCOM-MOOSRA: new MCDM-based knowledge-driven procedures for mineral potential mapping in greenfields," *SN Appl. Sci.*, vol. 3, pp. 1–19, 2021.

[11] A. Elsayed, "TrS-RAM: Leveraging Novel MCDM Techniques for Evaluating Sustainability of Fuel Cell Vehicles Based on Tree Soft Technique," *HyperSoft Set Methods Eng.*, vol. 1, pp. 46–58, 2024.

[12] S. F. AL-baker, I. El-henawy, and M. Mohamed, "Pairing New Approach of Tree Soft with MCDM Techniques: Toward Advisory an Outstanding Web Service Provider Based on QoS Levels," *Neutrosophic Syst. with Appl.*, vol. 14, pp. 17–29, 2024.

[13] A. Alqazzaz and K. M. Sallam, "Evaluation of sustainable waste valorization using treesoft set with neutrosophic sets," *Neutrosophic Sets Syst.*, vol. 65, pp. 151–160, 2024.

[14] F. Smarandache, *Practical applications of IndetermSoft Set and IndetermHyperSoft Set and introduction to TreeSoft Set as an extension of the MultiSoft Set*. Infinite Study, 2022.

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