A novel decision-making approach to evaluate transportation modes in a sustainable, agile and resilient supply chain network under uncertainty

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Abstract

One of the crucial issues in supply chains is the selection of an appropriate transportation mode for logistics operations. Various criteria and factors influence this decision, and it can vary across different supply chains. The objective of this paper is to evaluate transportation modes for the medical equipment supply chain based on sustainability, agility, and resilience criteria under uncertain conditions. Considering the significant impact of uncertainty in different scenarios, the evaluation of transportation modes needs to be conducted accordingly. Therefore, the Stochastic Fuzzy Best Worth Method (SFBWM) is utilized for this purpose and the indicators are assessed. The findings indicate that cost, speed, carrying capacity, flexibility, and national economy are the most important indicators. The main contribution of this study is the presentation of a developed approach using the Fuzzy Inference System (FIS). In this approach, the evaluation indicators are hierarchical and weighted, and the Hierarchy Weighted FIS (HWFIS) method is proposed. Based on the achieved results, agility was selected as the most important one, and sustainability and resiliency have the same rank with the same weights. Also, outputs demonstrate that the airplane is the most favorable option.

Keywords:

Transportation modes selection, Sustainability, Agility, Resiliency, Oxygen concentrator

1. Introduction

Supply Chain (SC) management plays a crucial role in today's competitive and modern marketplace. Nowadays, managers know that in order to increase the efficiency and productivity of their business and gain a competitive advantage, they need to develop an appropriate plan for their organization's SC [1,2]. In SC planning, one of the critical parts is the Distribution Network (DN) which can drastically improve the performance of the SC. An optimal plan for DN can dramatically reduce costs (especially transportation costs) and enhance customer satisfaction. In the strategic planning for the Distribution Centers (DCs), one of the critical tasks is to select the best transportation mode (TM) to ship products. Utilizing appropriate TM can drastically improve the performance of the DC and consequently the performance of the SC. Since the number and variety of the TMs have drastically increased in recent years, the mentioned task become more complex. In this regard, using decision-making frameworks can be useful.

In the SC field, In the beginning, and in the traditional approach, only the financial and economic dimensions of the SC were considered, and the researchers focused only on the financial goals [3,4]. After some time, with the increase of environmental concerns, the opinion of researchers was drawn to the problem of incorporating environmental considerations (such as reducing carbon emissions) in the SC management problem, which is called the green SC [5,6]. In the next research stream, the researchers also incorporated social issues in the design and management of the SCs, which led to the emergence of socially responsible SCs [7,8]. Finally, by integrating the financial, environmental, and social dimensions, the researchers introduced the sustainable supply chain that become a trending topic in the last two decades [9,10]. In recent years, due to some governmental and international considerations and regulations, incorporating sustainability dimensions into the business is a necessary issue.

By drastically increasing the fluctuation of the business environment and introducing unpredictable disruptions (e.g., COVID-19 pandemic), and also the dynamic nature of the marketplace, the attention of researchers and managers has attracted to the two crucial concepts namely resiliency and agility. In general, resilience is defined as the ability of a system to deal with disruptions [11,12], and agility is characterized as the capacity of a system to cope with the dynamic nature of the business environment [13,14]. Due to the crucial role of the mentioned concepts, they become as the main pillars of the emergence concepts named viability [15,16] and Industry 5.0 [17,18], which show that incorporating these critically important concepts into today's businesses.

Given the importance of the mentioned points, the current work aims at proposing a hybrid decision-making framework to select the best transportation mode for the DC in a sustainable supply chain. For this purpose, a list of indicators and alternatives are provided according to the literature and experts. Then, a recently introduced efficient method named the SFBWM is used to compute the importance of the indicators. In the next step, the WFIS is employed to evaluate the potential transportation modes. The main research motivation is that the appropriate transportation mode selection by considering the critically important metrics like sustainability, resilience, and agility, especially in the medical devices industry, can significantly improve the supply chain efficiency and effectiveness, which leads to enhancing customers satisfactions. Also, in comparison with the previous papers, the main advantage of this work is to develop an efficient hybrid fuzzy decision-making model to investigate the transportation mode selection problem.

The significant contributions of the current research are related to examining the transportation modes evaluation problem based on the sustainability, agility, and resilience indicators for the first time. In this regard, to the best of our knowledge, no academic work has previously investigated the transportation evaluation problem with the mentioned features (i.e., sustainability, agility, and resilience). Moreover, regarding the methodology, this study has developed an efficient and novel hybrid approach novel by integrating the FSBWM and HWFIS methods that is the first combination of these methods in the literature. All in all, this work contributes to the literature by developing a novel and effective hybrid method to investigate the transportation mode selection problem based on the sustainability, agility, and resilience indicators for the first time.

In this paper, Section 2 presents the literature, Section 3 describes the methodology, Section 4 introduces the case study, Section 5 presents the computational results, and Section 6 provides the conclusions.

2. Literature review

In the field of evaluating various components of the supply chain, several studies have been conducted. For instance, Nag and Helal [19] proposed a fuzzy approach for supplier selection in a pharmaceutical distribution system. The Fuzzy Technique for Order of Preference by Similarity to Ideal Solution (Fuzzy TOPSIS) method was utilized by them, where evaluation criteria included quality, delivery, price, agility, service level, and brand of the organization. The results showed that the Fuzzy TOPSIS model can be effectively applied in uncertain environments and has the potential for replication in other scenarios with similar dynamic operational environments. Another study by Wang et al. [20] concentrated on risk management in the distribution of perishable food items. Their primary goal was to anticipate or even manage food safety hazards during the distribution process of perishable food items. They proposed a model that addressed a vehicle routing problem considering food safety risk coefficient and time window constraints to minimize distribution costs. To solve the problem, they employed the Whale Optimization Algorithm based on Weight-Parameter Optimization (WPWOA), which demonstrated superior performance compared to other algorithms in most evaluation criteria and prevented premature convergence. WPWOA exhibited faster and more robust performance than the original WOA algorithm. Liao et al. [21] conducted an evaluation and selection of distribution centers in a cold supply chain. They utilized a developed combined compromise solution method in the Pythagorean fuzzy environment, which was introduced for the first time. They incorporated sustainability indicators in evaluating the distribution centers, where coherence indicators of the distribution center, regional conditions, and pollution level were the most important criteria in their evaluations.

Wahyuni et al [22] presented a new method for evaluating and selecting distributors. They utilized the Multi-Attribute Utility Theory (MAUT) approach to evaluate the distributors. The identified key criteria in evaluating distribution networks were product quality, reasonable price, strategic location, and responsiveness. According to their study, five distributors were selected as the top options. Shamsuzzoha et al. [23] designed a data-driven supply chain network in a pharmaceutical distribution company. In wholesale, the logistics process is a crucial capability, and optimizing this process can provide significant competitive advantages. Their objective was to examine the causes of supply chain gaps and ways to mitigate their impacts, focusing on minimizing travel costs for preventing environmental damage and providing advantages to the company's input process. The research results showed that the central pipeline system could enhance information flow, increase cargo capacity, and reduce CO_2 emissions to support an environmentally sustainable and resilient supply chain and logistics processes. Sazvar et al. [24] introduced a data-driven approach to evaluate and select suppliers, focusing on sustainability and resilience paradigms. They identified 22 criteria and adopted the Fuzzy Best Worth Method (FBWM) to assign weights to these indicators. Additionally, a Fuzzy Inference System (FIS) was utilized to establish the performance measurement rules. Machine learning algorithms were employed to construct the supplier evaluation model. The findings revealed that managers prioritized responsiveness and capability as crucial factors. Moreover, other companies can utilize this model for supplier selection based on historical data. Vats et al, [25] proposed a grey decision-making approach for distributor selection in the supply chain. They conducted a case study on an automotive parts manufacturer, evaluating four suppliers using eight criteria. The findings revealed that cost, delivery speed, and order handling were the most important evaluation criteria.

ForouzeshNejad [26] conducted a study that centered around the evaluation of agile and sustainable suppliers in the context of the Fourth Industrial Revolution. To achieve this, they assigned weights to the indicators using the rough best-worst method (RBWM). Subsequently, the suppliers were evaluated using the multi-attributive border approximation area comparison (IR-MABAC) method. The identified key criteria in the evaluations were production flexibility, cost, trustworthiness, smart factory, and quality. Nayeri et al. [27] presented a data-driven model for evaluating suppliers in the supply chain and allocating orders to them. They employed the SBWM method for supplier evaluation and utilized data-driven algorithms to parameterize the supply chain network, considering uncertainty in estimation. Finally, order allocation to suppliers was performed. The key identified indicators in their study included cost, agility, and pollution production. Zhao et al. [28] proposed an integrated approach based on the Multiple-Criteria Decision-Making (MCDM) theory for selecting sustainable and resilient suppliers and allocating orders for distribution. Their two-level research involved supplier evaluation and selection in the first phase, followed by order allocation to the selected suppliers. Supplier evaluation in their study was performed using a developed VIKOR approach, and the order allocation model was solved using the idealized programming approach. The key evaluation indicators for suppliers were timely delivery of products and crisis management capability. Muneeb et al. [29] presented a model for selecting suppliers-manufacturers and distributors for remanufactured products in the context of a circular economy. Since distributors play the role of supplying raw materials through returned products in some cases in the circular economy, this model focuses on their integrated evaluation. The key criteria in the evaluation performed in the proposed model were cost reduction, environmental impact reduction, and revenue maximization.

Bouraima et al. [30] evaluated rail transport systems for sustainable transportation. They used the hybrid IR-SWARA-CoCoSo method for the evaluation. The findings indicate that the developed hybrid method performs well and also identify that information systems are the most critical challenge for selecting rail transport systems. Çelikbilek et al. [31] developed a multi-criteria decision-making model in a grey environment to evaluate and select public transportation systems. They used AHP, BWM, and MOORA methods for the evaluation. Their assessment criteria included sustainability and passenger satisfaction, based on which different systems were evaluated and analyzed. Oubahman & Duleba [32] developed a fuzzy model for selecting public transport modes. They combined the fuzzy approach with the PROMETHEE method, and their developed method showed good performance in evaluations. Their model acts as a basis for a fuzzy inference system that can facilitate mode selection for passengers in a changing environment. The results support the quality of underground transportation services. Batool et al. [33] promoted sustainable transportation. They collected data through a survey of 260 students and employees to determine if their choice of various transport modes contributes to sustainable transportation. The results indicate that URICA effectively identifies the five stages of change. As individuals progress through these stages, both decision balance and self-efficacy behavior increase, which also holds true for the adoption of active transportation modes. Bilişik et al. [34] developed a new approach based on the fuzzy intuitionistic CRITIC-TOPSIS for selecting the transportation mode of a glass manufacturing company. They developed a hybrid decision-making method based on interval-valued intuitionistic fuzzy sets (IVIFS), which performed well in the evaluations. Their findings indicate that rail transport is selected as the most suitable mode for the glass manufacturing company.

The summary of the literature review conducted is presented in Table 1.

As shown in the literature, the transportation model selection problem is one of the importance issues in the logistics research area that significantly attracted the attention of researchers in recent tears. However, several research gaps have been observed in this field. For instance, the simultaneous consideration of the agility, sustainability, and resilience indicators in the mentioned problem has been ignored by previous works. Also, the application of the data-driven approaches has been rarely addressed in the literature. Overall, the summary of the literature review indicates that the evaluation of the transportation modes in supply chain networks has been examined in various forms. However, it is noteworthy that the simultaneous consideration of indicators related to resilience, sustainability, and their combination with agility in the evaluation of transportation modes is not observed in the reviewed studies. Additionally, taking into account uncertainty in evaluations is important. Therefore, based on the aforementioned explanations, the main innovations of this study, aimed at addressing the research gaps, are as follows:

- Simultaneous consideration of indicators related to sustainability, resilience, and agility in the evaluation of transportation modes for the first time.
- Accounting for uncertainty in the evaluations of transportation modes.
- Evaluation of transportation modes of oxygen concentrator devices.
- Introducing a novel hybrid approach, developed FSBWM-HWFIS.

3. Methodology

3.1. Stochastic Fuzzy BWM

As aforementioned, in this study, the SFBWM has been employed to calculate the weight of indicators. In this section, we have briefly defined this approach. The SFBWM is the extended form of the traditional BWM to deal with uncertain environment. Indeed, this efficient approach has been developed to tackle both event-based and epistemic uncertainties [27]. The main advantages of this method are as follows: (i) this approach enhances the reliability of the outputs due to its structured pairwise comparison which leads to reduce computational bar [27,35], (ii) this method can deal with mixed uncertainty (fuzzy-scenario) [27], (iii) this method easily can combine with different methods [27,35]. In the following, we have described the steps of the SFBWM. Suppose that there are S scenarios indexed by s and N criteria indexed by n. The probability of each scenario is denoted by PS_s such that $\sum_s PS_s = 1$. Moreover, let B and W respectively represent the Best and the Worst indicators determined by decision-makers. By considering $\tilde{a}_{Bjs} = (l_{Bjs}, m_{Bjs}, u_{Bjs})$ as the fuzzy comparison vector between the best indicator and the others, $\tilde{a}_{jws} = (l_{jws}, m_{jws}, u_{jws})$ as the fuzzy comparison vector between the worst indicator and the others, and $\tilde{w}_{sj} = (l^{w}_{js}, m^{w}_{js}, u^{w}_{js})$ as the fuzzy weights of the indicators, the mathematical formulation of the SFBWM can be written as Model (1) [27] where w_j is weight of j^{th} criterion and. It should be noted that in each $\tilde{\xi}^{*}_{s} = (k^{*}_{s}, k^{*}_{s}, k^{*}_{s})$ scenario, the comparison vectors can be formed based on Table 2. Finally, the Consistency Ration (CR) can be calculated according to Table 3 and Relation (2).

$$Minimize \sum_{s} PS_{s} \tilde{\xi}_{s}$$

subject to

$$\left| \frac{(l^{w}_{Bs}, m^{w}_{B}, u^{w}_{Bs})}{(l^{w}_{js}, m^{w}_{js}, u^{w}_{js})} - (l_{Bjs}, m_{Bjs}, u_{Bjs}) \right| \le (k^{*}_{s}, k^{*}_{s}, k^{*}_{s}) \qquad \forall j, s,$$

$$\left| \frac{(l^{w}_{js}, m^{w}_{js}, u^{w}_{js})}{(l^{w}_{Ws}, m^{w}_{Ws}, u^{w}_{Ws})} - (l_{jWs}, m_{jWs}, u_{jWs}) \right| \le (k^{*}_{s}, k^{*}_{s}, k^{*}_{s}) \qquad \forall j, s,$$

$$\sum_{j=1}^{n} R(w\tilde{s}_{js}) = 1 \qquad \forall s, \qquad (1)$$

$$l^{w}_{js} \le m^{w}_{js} \le u^{w}_{js} \qquad \forall j, s,$$

$$w_{j} = \sum_{s} P_{s} R(w\tilde{s}_{js}) \qquad \forall j,$$

$$l^{w}_{js} \ge 0 \qquad \forall j, s.$$

$$CR = {\xi^*}/{CI} \tag{2}$$

3.2. Hierarchy Weighted FIS

In this study, a hierarchical weighted fuzzy inference system (HWFIS) is used to evaluate the efficiency of transportation modes. This method assesses options based on rules derived from weighted input variables[37,38]. The HWFIS has a multi-layered structure that calculates the evaluation labels of options corresponding to each level[39,40]. The HWFIS method has the capability to handle uncertainty and, due to its use of fuzzy rules, can make complex decisions [41]. Additionally, this approach does not require complex modeling and can be implemented using expert knowledge [24]. These advantages have led to the development of this method in the present study.

The steps of this method are generally as follows[41,42]:

- ***Step 1 (Defining Inputs and Outputs):*** In the first step, the input and output variables of the system are defined. In this study, the input variables are the evaluation indices of the transportation modes, and the output variable is the efficiency of the transportation mode. Additionally, the range of values for the variables is defined at this stage.
- ***Step 2 (Defining Fuzzy Sets):*** At this stage, fuzzy sets for each of the input and output variables are defined, and appropriate membership functions are selected for each set. In this study, triangular membership functions are chosen.
- ***Step 3 (Determining Fuzzy Rules):*** Using the "IF-THEN" structure, fuzzy rules are defined. Each rule is defined as a fuzzy condition for the inputs and a fuzzy result for the outputs.
- ***Step 4 (Assigning Weights to Rules):*** The weight of each index in each rule is determined, and their influence on determining the result is applied in the system. In this study, the weights are calculated using the SFBWM method.

- ***Step 5 (Evaluating Fuzzy Rules):*** For each specified input, the membership degree of each input in the corresponding fuzzy sets is calculated. These membership degrees are used to evaluate the fuzzy rules, and the fuzzy result of each rule is obtained.
- ***Step 6 (Combining Results):*** At this stage, the fuzzy results of each rule are combined according to their weights. This combination is done as a weighted sum.
- ***Step 7 (System Output):*** The value of the output variable label is reported as the final output of the decision-making system.

These steps ensure that the HWFIS method effectively leverages fuzzy logic to handle complex decision-making scenarios with a higher degree of precision and flexibility.

The reason for developing the FIS in a hierarchical and weighted format is to incorporate the importance and weight of each index in evaluating transportation modes. According to the defined structure, the weights of the indices are applied in the evaluation. Additionally, the hierarchical structure allows for the separate assessment of the accuracy and efficiency of each transportation mode based on the category of indices.

3.3. Hybrid Methodology

A new hybrid decision-making approach is presented in the current article for evaluating transportation modes. Due to uncertainties in different conditions, for example, during a flood, air transportation becomes more convenient than ground transportation. Therefore, evaluations should consider various scenarios. In this regard, the SFBWM approach is utilized to weight the evaluation indicators, which are identified and categorized into three groups: sustainability, resilience, and agility. The SFBWM approach considers different scenarios in a fuzzy framework. Once the weights of the indicators are determined using the HWFIS approach, which is the main objective of this study, the transportation modes are weighted and prioritized. The hierarchical FIS approach is employed for evaluating transportation modes, where the scores of each category within sustainability, resilience, and agility are specified. Then, based on the weights of the categories, the final scores and prioritization of the transportation modes are determined. According to the explanations, the steps of this article are shown in Figure 1.

The advantages of this proposed method over other approaches include the following:

- Dealing with uncertainty by considering various scenarios in evaluating the indicators.
- The ability to define a large number of indicators in evaluations due to the hierarchical structure of HWFIS.
- Incorporating the weighting of indicators in evaluating transportation modes using the HWFIS method.

4. Case study

The case study of this paper evaluates transportation modes for the movement of medical equipment, specifically oxygen concentrators, in Iran and the countries around the Persian Gulf. Since this exchange is bilateral, all transportation methods such as air, sea, rail, and various land routes can be utilized. The supply of medical equipment, specifically oxygen concentrators, faces various challenges, particularly in Iran, which are often related to transportation. Ensuring precise timing in the transportation and delivery of equipment is crucial to meet hospital needs and address patient requirements. This challenge becomes especially significant during critical periods, such as the COVID-19 pandemic, and poses extensive issues for organizations. Additionally, the conditions of transporting these devices are important, making the evaluation of transportation modes essential to address this matter effectively. In this regard, the overall transportation structure studied is illustrated in Figure 2.

The evaluation of transportation modes considers the criteria of sustainability, resilience, and agility. The selection of sustainability criteria is motivated by the importance of environmental issues and job creation. Additionally, considering the significance of resilience and crisis management in transportation, resilience criteria are included. Alongside these considerations, agility criteria are also important, as they allow for the assessment of the speed of movement. The identified criteria in this paper are presented in Tables 4 to 6.

To collect the necessary data for this study, a survey questionnaire was used to gather expert opinions. In this context, three groups of experts were formed to conduct the evaluations based on their insights. Since the case study of this research focuses on oxygen concentrators specifically for hospitals, the first group of experts consists of senior managers from hospitals and organizations supplying oxygen concentrators within the country; this group includes 7 members. The second group comprises operational managers from hospitals and companies supplying oxygen concentrators within the country, who have precise operational experience in this field, and includes 9 members. The third group consists of consultants in the field of hospital transportation and supply, who are academic professors and experts with extensive experience in transportation projects; this group also includes 7 members. The questionnaire data were collected collectively from these individuals.

5. Result

5.1. Weighting of criteria with FSBWM

In this section, we have presented the outputs obtained from the SFBWM. It should be noted that for data gathering, three groups of experts help us and the comparison vectors have been formed based on the average of experts' opinion. In this way, Table 7 shows the weight of indicators. As can be seen in Table 7, As shown in Table 3, among the aspects, agility was selected as the most important one, and sustainability and resiliency have the same rank with same weights. Among the agility criteria, cost and quality are selected as the vest indicators. Moreover, among the resiliency indicators, flexibility and carrying capacity are calculated as the most important ones. Finally, among the sustainability criteria, waste management and greenhouse gas emission are identified as the most important indicators. Moreover, Table 8 demonstrates the value of CR for each step. According to Table 8, for all steps, the value of CR is less than 0.1 and close to zero, which confirms the reliability and validity of the achieved outputs.

5.2. Evaluation of transportation mode with Hierarchy Weighted FIS

In this section, the evaluation of transportation modes in accordance with the criteria of sustainability, resilience, and agility is presented using a hierarchical weighted fuzzy inference system approach. In this new approach, in the first step, transportation modes are evaluated separately based on the dimensions of agility, resilience, and sustainability, and then a final evaluation is provided. The weight allocation structure for the evaluations is based on pentagonal fuzzy numbers, as shown in Table 9.

The hierarchical structure of evaluation of transportation modes is also shown in Figure 3. The hierarchical structure indicates that, according to the evaluations, the labels for agility, resilience, and sustainability are determined first, and then the final label for each transportation mode will be calculated. It is important to note that the weights of the indices, which were calculated in the previous stage, have been applied in this evaluation.

According to the evaluation structure, Figure 4 presents the membership functions, which visually demonstrate how the indices are evaluated in the fuzzy system. The membership functions for the first index of each category of evaluation indices are shown. Each curve represents a linguistic variable for defining the corresponding index, which is defined with five levels: Very low efficiency, Low efficiency, Average performance, High efficiency, and Very high efficiency.

In accordance with the structure defined in Figure 3 and the membership functions in Figure 4, some of the evaluation and assessment rules for transportation modes developed according to the fuzzy inference system include the following. It is important to note that the following rules are only three examples of the inference system rules.

- If C1= Very high efficiency, C5= High efficiency and C9= High efficiency; Then transportation mode is High efficiency.

- If C1= Average efficiency, C5= Average efficiency and C9= Low efficiency; Then transportation mode is Average efficiency.

- If C1= High efficiency, C5= Average efficiency and C9= Low efficiency; Then transportation mode is Average efficiency.

Based on the hierarchical fuzzy structure mentioned, six transportation modes are examined and evaluated. The transportation modes include freight trains, trucks, mini trucks, airplanes, ships, and boats, and their evaluations are presented in Tables 10 to 15. It is worth noting that all the criteria have been assessed from a positive perspective. For example, if a transportation mode receives a VH score in terms of breakdown rate, it criteria a lower breakdown rate for that mode.

According to the outputs from the above tables, it can be observed that airplanes are the preferred choice, ranking the highest among the transportation modes. In terms of agility, airplanes excel due to their high speed and relatively lower breakdown rates compared to other modes. In terms of resilience, ships and airplanes are the top choices. For sustainability, airplanes, ships, and boats are the preferred options. In general, the ranked evaluation of transportation modes is as follows: airplanes, ships, trains, boats, trucks, and vans.

5.3. Effectiveness of the employed SFBWM

In this section, to assess the performance of the employed SFBWM, we have compared its outputs with another method (FAHP). In this regard, Figure 5 compares the weights obtained by the SFBWM and FAHP. As can be seen in this figure, many of obtained weights are close to each other with confirm the validity of the achieved results. On the other hand, to assess the reliability of the employed method, we generate 5 different decision-making problems and calculate the weight of indicators using the SFBWM and FAHP. Then, we compare their CRs. In this regard, Figure 6 shows the CRs achieved by SFBWM and FAHP. Based in this figure, the CR of the SFBWM is less than the CR of the FAHP that demonstrates its reliability.

5.4. Validation of the HWFIS method

To validate the proposed method, the evaluation of transportation modes was also conducted using the combined methods of FBWM-FVIKOR and FAHP-FTOPSIS, and they were compared to examine the credibility of the proposed approach. The comparison of rankings for different transportation modes is presented in Table 16. It is observed that the results of the developed method are consistent with other reputable methods, indicating the accuracy and validity of the approach developed in this study. A notable point is the flexibility and extensibility of the model presented in this paper compared to other methods in evaluating different options, as it has the capability to define various scenarios in a fuzzy environment.

5.5. Sensitivity analysis

In this section, the results of the sensitivity analysis of the changes in criteria on the final outcome, which is the efficiency of the transportation mode, are examined. Generally, for conducting the sensitivity analysis, the values of the criteria have been varied to different extents to monitor the impact on the efficiency labels of the options. The most important indices in evaluating the efficiency of transportation modes are Flexibility, National Economy, Speed, Carrying Capacity, Waste Management, and Failure Rate. To monitor the sensitivity analysis of each of the important criteria mentioned, the efficiency value of each criteria was increased incrementally so that the efficiency of the transportation mode could be assessed accordingly. Figure 7 shows the incremental changes and their impact on the efficiency of the transportation mode. For instance, if the value of the Flexibility criteria moves from Low Efficiency to Average Efficiency, the efficiency of the transportation mode increases by one step. It is observed that changes in the Speed criteria have the greatest impact on the efficiency of the transportation mode.

5.6. Theoretical implications

This research has focused on the evaluation process of transportation modes in a logistics system with agility, sustainability, and resilience dimensions by developing a data-driven method. In this regard, this work contains several theoretical implications that are presented in the following. In this regard, literature showed that the simultaneous consideration of the agility, resilience, and sustainability metric in the transportation mode section problem has been ignored by researchers. Therefore, the main theoretical implication of this work relates to the way of considering these dimensions in the mentioned problem. Also, based on the literature, considering the uncertain environment in the transportation model selection problem has been rarely addressed in the literature. In this way, another theoretical implication of this work is to develop an efficient data-driven method to deal with fuzzy uncertainty in the considered decision-making problem. Overall, the main theoretical contribution of this work is to develop an efficient hybrid fuzzy decision-making model to investigate the transportation mode selection problem.

6. Conclusions

This study presents a new combined approach for evaluating transportation modes under conditions of uncertainty. The evaluation criteria for transportation modes in this article include sustainability, resilience, and agility. In logistics and supply chain transportation, agility is highly important, as the speed and timely delivery of products, especially in the field of medical equipment and hospital supply chains, are crucial. Another notable point is that alongside agility, the resilience of transportation modes is also significant. The ability to manage crises, cope with potential risks, and ensure the security and safety of equipment during transportation are essential factors addressed in the evaluations of this study. Alongside these criteria, considering the economic and environmental aspects alongside social issues, sustainability criteria have always been necessary and important. Therefore, the evaluations in this study are based on the criteria of agility, resilience, and sustainability.

The findings indicate that flexibility, speed, carrying capacity, environmental impacts, and national economic impacts are the most important evaluation criteria. From a thematic perspective, evaluations of distribution networks or distribution systems in supply chains have been conducted based on sustainability criteria [23], agility criteria (Liao et al., 2020), and resilience criteria (Nayeri et al., 2023). However, considering the simultaneous assessment of the three paradigms of sustainability, agility, and resilience in the evaluations has not been found in previous studies, making this article significantly innovative. Additionally, considering uncertainty in the evaluations is another key issue addressed in this study.

The methodology used in this article is also proposed for the first time. The developed Best-Worst Fuzzy methodology is used, which takes into account various scenarios in evaluating the criteria. However, the main innovation of this approach lies in the hierarchical structure and weighted FIS, introducing a novel approach called Hierarchy Weighted FIS. In this approach, efficiency labels for transportation modes are determined based on the criteria of agility, resilience, and sustainability in each category, and then the final ranking is performed based on their outputs. With such a design, any number of criteria can be considered in the evaluations.

According to the results obtained in this article, it can be observed that for the design of hospital equipment supply chain networks, despite various transportation options such as land, sea, and air routes, the best option in terms of agility, speed, and considerations of resilience and sustainability is air transportation. Air transportation has higher crisis management capabilities and risk management compared to maritime and land options, as well as superior speed and agility compared to other options. On the other hand, from an environmental and national economic perspective, air transportation is also more efficient, making it the preferred choice for medical equipment transportation.

One of the limitations of this work is that it only focused on the fuzzy uncertain environment. In this regard, future studies can consider other uncertain environment like grey or rough ones and develop efficient approaches to deal with. Also, another limitation of this article is to ignore some crucial indicators. In this regard, future researchers can consider other important indicators like viability and globalization.

It is also suggested that the evaluations conducted within this framework be examined for other industries and case studies, and their results be compared with the findings of this article. An important point is the development of this structure for evaluating suppliers from different countries, considering transportation modes, where the evaluations must take into account the political conditions of the countries and their regulations in supplier assessments. Additionally, in the future development of the proposed method, it is recommended to incorporate random and scenario-based structures into the HWFIS approach to align the evaluations with various scenarios.

Statements and Declarations

Ethical approval and Informed Consent

The authors certify that this paper does not contain any studies or involvement with human participants or animals performed by any authors in any organization or entity with any financial or nonfinancial interest in the subject matter or materials discussed in this paper.

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Table 1. Summary of literature review

Author	Aim	Dimensions						Methods	Case study
		Economic	Social	Environmental	Agility	Resilience	Uncertainty		
(19)	Evaluation of distribution system suppliers	*			*			Fuzzy TOPSIS	drug
(20)	Investigating risk management in the perishable food distribution network	*		*				WPWOA	FMCG
(21)	Evaluation of the distribution network	*	*	*				Pythagorean fuzzy CoCoSo	Cold supply chain
(22)	Distributor evaluation	*			*			MAUT	Multi-product stores
(23)	Distribution network design	*	*	*				Mathematical model	drug
(24)	Supplier evaluation and selection	*	*	*		*		FBWM-ML	drug

(25)	Evaluation and selection of distributors	*			*			Gray MCDM	Auto Parts
(26)	Evaluation and selection of suppliers in distribution	*	*	*	*			RBWM - IR-MABAC	Medical Equipment
(27)	Evaluation of suppliers and allocation of orders for distribution to them	*		*		*	*	SBWM – DDFRS	Medical Equipment
(28)	Evaluation of suppliers and allocation of orders for distribution to them	*	*			*		VIKOR-MODM	---
(29)	Evaluation of supplier, producer and distributor network	*		*				MODM	Home Appliances
(30)	Evaluation of the rail transport system for sustainable development	*	*	*				IR-SWARA-CoCoSo	railroad transportatio n
(31)	Evaluation of the public transportation system	*	*					AHP-BWM-MOORA	---
(32)	Evaluation of the public transportation system	*	*	*				Fuzzy PROMETHEE	---
(33)	Evaluation of public transportation system to achieve sustainability	*	*	*				Statistical analyses	---
(34)	Evaluation of product transfer modes of transportation							CRITIC-TOPSIS	Glass manufacturer
This Study	Evaluation of transportation modes in the distribution sector	*	*	*	*	*	*	FSBWM-WFIS	Oxygen generator

Table 2. Linguistic Variables in the SFBWM [36].

Language terminology	Membership function
Fundamental Significance (FS)	(3.5, 4, 4.5)
Extremely Significant (ES)	(2.5, 3, 3.5)
Moderately Significant (MS)	(1.5, 2, 2.5)
Somewhat Significant (SS)	(0.6667, 1, 1.5)
Equally Significant (ES)	(1, 1, 1)

Table 3. Values defined for the CI [36].

	(ES)	(SS)	(MS)	(ES)	(FS)
$\tilde{a}_{BW}$	(1, 1, 1)	(0.667, 1, 1.5)	(1.5, 2, 2.5)	(2.5, 3, 3.5)	(3.5, 4, 4.5)
CI	3.00	3.80	5.29	6.69	8.04

Figure 1. Flowchart of article steps

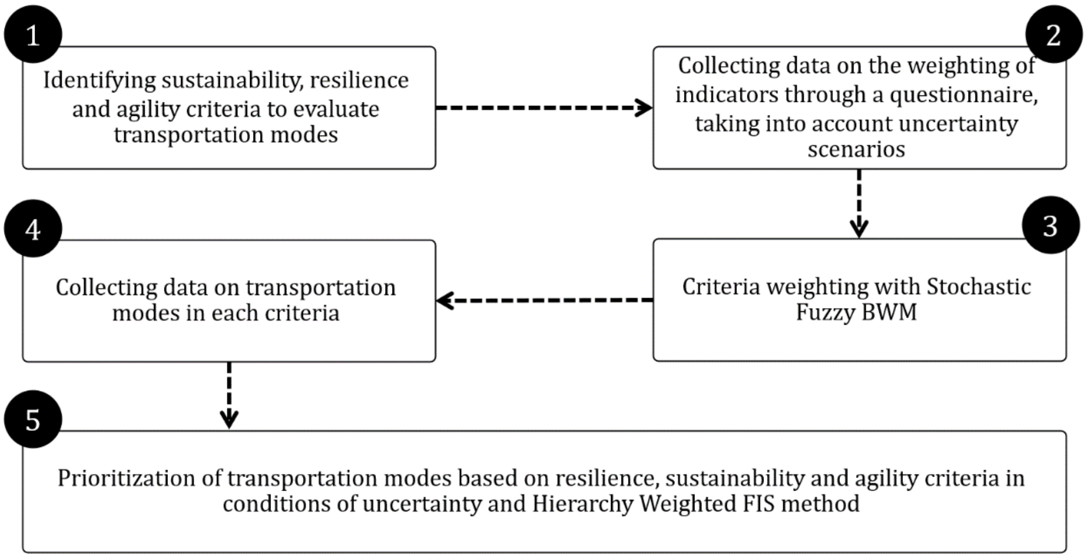


Figure 2. Case study

Table 4. Agility criteria for evaluation of transportation modes

Criteria	Definition	Reference
(C01) Cost	The effectiveness of the transport mode in terms of prices	Wahyuni et al, 2020 Nag & Helal, 2016
(C02) Speed	The speed of the transport mode in the movement of products	Wahyuni et al, 2020 Nayeri et al, 2023
(C03) Transportation	The flexibility and reliability of the transport mode in terms of transportation	Nayeri et al, 2023
(C04) Failure rate	Failure rate of devices and facilities related to the mode of transportation	Wahyuni et al, 2020

Table 5. Resilience criteria for evaluation of transportation modes

Criteria	Definition	Reference
(C05) Carrying capacity	Transport capacity per transport trip	Sazvar et al, 2022 Nayeri et al, 2023
(C06) Flexibility	The flexibility of the transport mode in the amount of cargo carried per trip	Zhao et al, 2023
(C07) Safety	Cargo safety level during loading and handling	Nayeri et al, 2023
(C08) Natural crisis management	The ability to manage transportation during natural crises such as floods and earthquakes	Zhao et al, 2023 Sazvar et al, 2022

Table 6. Sustainability criteria for evaluation of transportation modes

Criteria	Definition	Reference
(C09) Waste management	The transport mode's capability in managing and reducing wastes	Zhao et al, 2020 Sazvar et al, 2022
(C10) National economy	The extent of the distributor's impact on the national economy	Shamsuzzoha et al, 2020
(C11) Job opportunities	Job opportunities created by the transport mode	Zhao et al, 2020
(C12) Energy consumption	Fossil energy consumption of transportation modes	Jacyna et al, 2014
(C13) Greenhouse gas emission	The transport mode's ability to control and reduce the greenhouse gas emission	Zhao et al, 2020 Jacyna et al, 2014

Table 7. The weights of the indicators

Aspect	Aspect's weight	Criteria	Criteria's initial weight	Criteria's final weight $(\textit{Aspect's weight} \times \textit{Criteria's initial weight})$
Agility	0.34	Cost	0.26	0.0884
		Speed	0.26	0.0884

		Transportation	0.23	0.0782
		Failure rate	0.25	0.085
Resiliency	0.33	Carrying capacity	0.26	0.0858
		Flexibility	0.29	0.0957
		Safety	0.22	0.0726
		Natural crisis management	0.23	0.0759
Sustainability	0.33	Waste management	0.26	0.0858
		National economy	0.27	0.0891
		Job opportunities	0.18	0.0594
		Energy consumption	0.14	0.0462
		Greenhouse gas emission	0.15	0.0495

Table 8. The values of CRs

Step	**CR**
Aspects	0.0495
Agility criteria	0.06186
Resiliency criteria	0.05813
Sustainability criteria	0.06725

Table 9. Fuzzy numbers used in evaluations

Scale	Triangular fuzzy number	Verbal expression
Very low efficiency	(1,1,1)	VL
Low efficiency	(1,3,5)	L
Average efficiency	(3,5,7)	M

High efficiency	(5,7,9)	H
Very high efficiency	(7,9,11)	VH

Figure 3. HWFIS structure

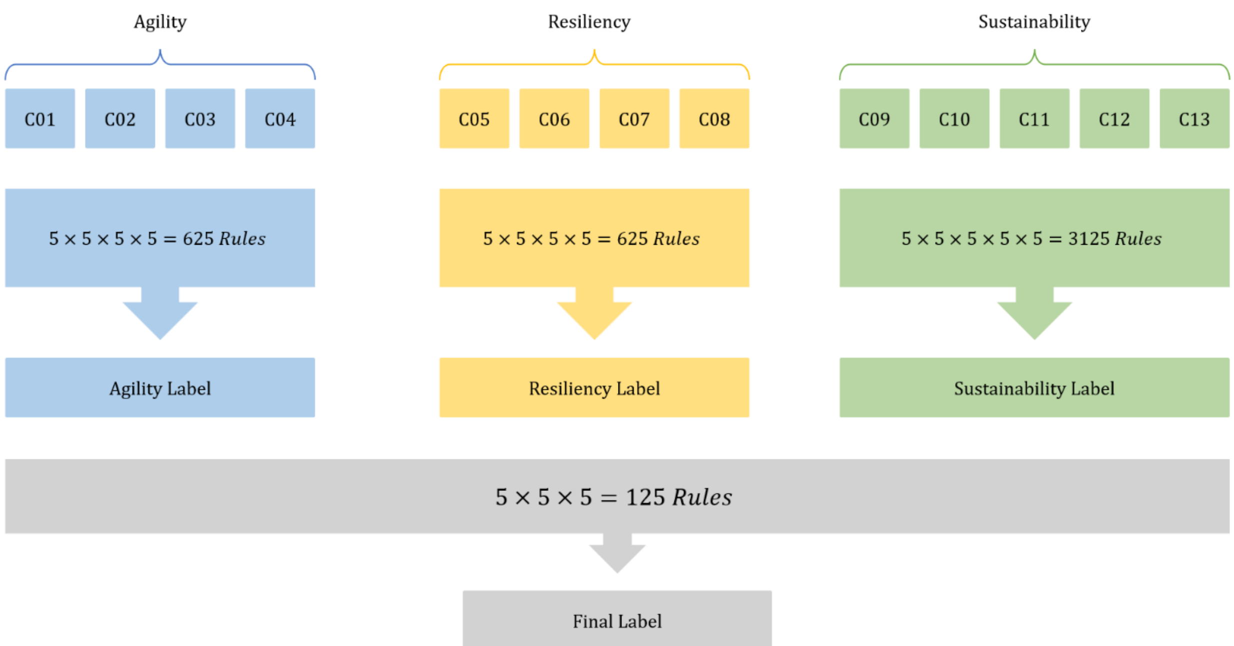


Figure 4. Membership function chart

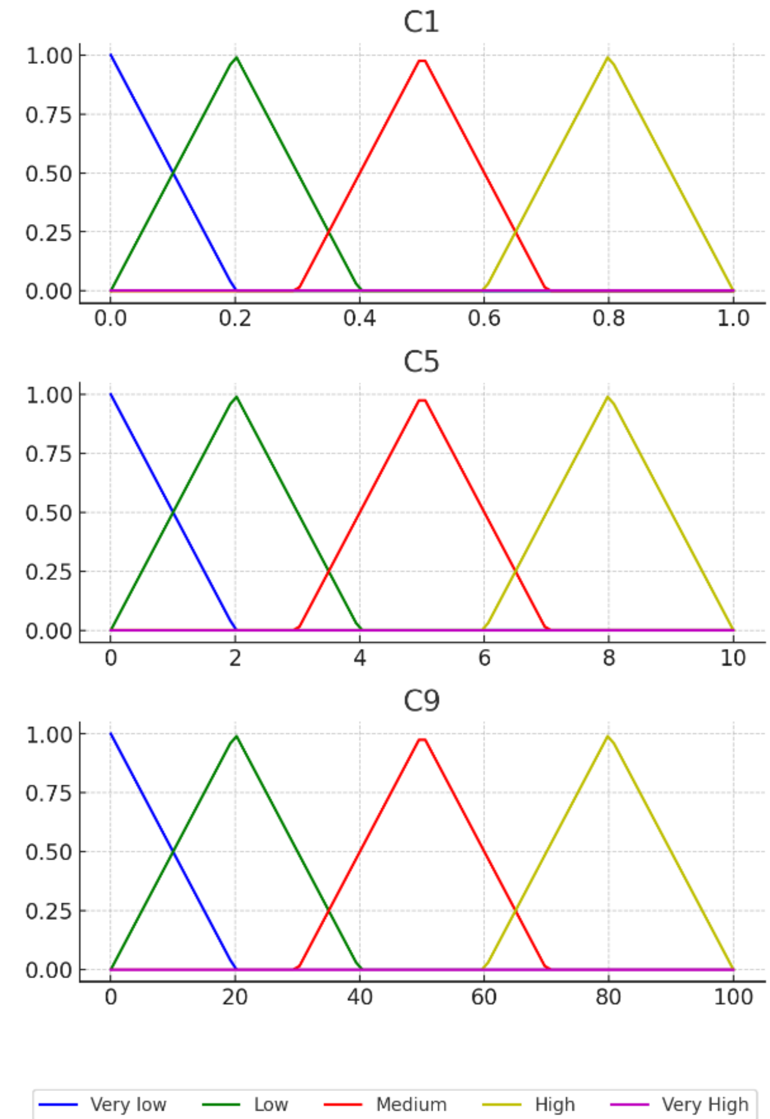


Table 10. Evaluation of train transportation mode

Criteria	Value	Category label	Final label
C01	H	H	M
C02	VH		
C03	M		
C04	H		
C05	M	M	
C06	M		
C07	VH		
C08	M		
C09	H	M	
C10	H		

C11	L		
C12	M		
C13	M		

Table 11. Evaluation of truck transportation mode

Criteria	Value	Category label	Final label
C01	H	L	L
C02	L		
C03	M		
C04	L		
C05	L	L	
C06	L		
C07	L		
C08	VL		
C09	M	M	
C10	L		
C11	M		
C12	M		
C13	L		

Table 12. Evaluation of mini truck transportation mode

Criteria	Value	Category label	Final label
C01	H	M	L
C02	M		
C03	M		
C04	L		
C05	VL	L	
C06	M		
C07	L		
C08	VL		
C09	M	L	
C10	L		
C11	L		
C12	M		
C13	L		

Table 13. Evaluation of airplane transportation mode

Criteria	Value	Category label	Final label
C01	M	VH	VH
C02	VH		
C03	VH		
C04	VH		
C05	H	H	
C06	H		
C07	H		
C08	H		
C09	H	H	
C10	VH		
C11	M		

C12	H		
C13	H		

Table 14. Evaluation of ship transportation mode

Criteria	Value	Category label	Final label
C01	M	M	H
C02	VL		
C03	H		
C04	H		
C05	VH	H	
C06	VH		
C07	H		
C08	M		
C09	VH	H	
C10	H		
C11	H		
C12	H		
C13	H		

Table 15. Evaluation of boat transportation mode

Criteria	Value	Category label	Final label
C01	VH	M	M
C02	M		
C03	L		
C04	L		
C05	L	L	
C06	M		
C07	VL		
C08	VL		
C09	VH	H	
C10	M		
C11	M		
C12	H		
C13	H		

Figure 5. The weights obtained by the SFBWM and FAHP

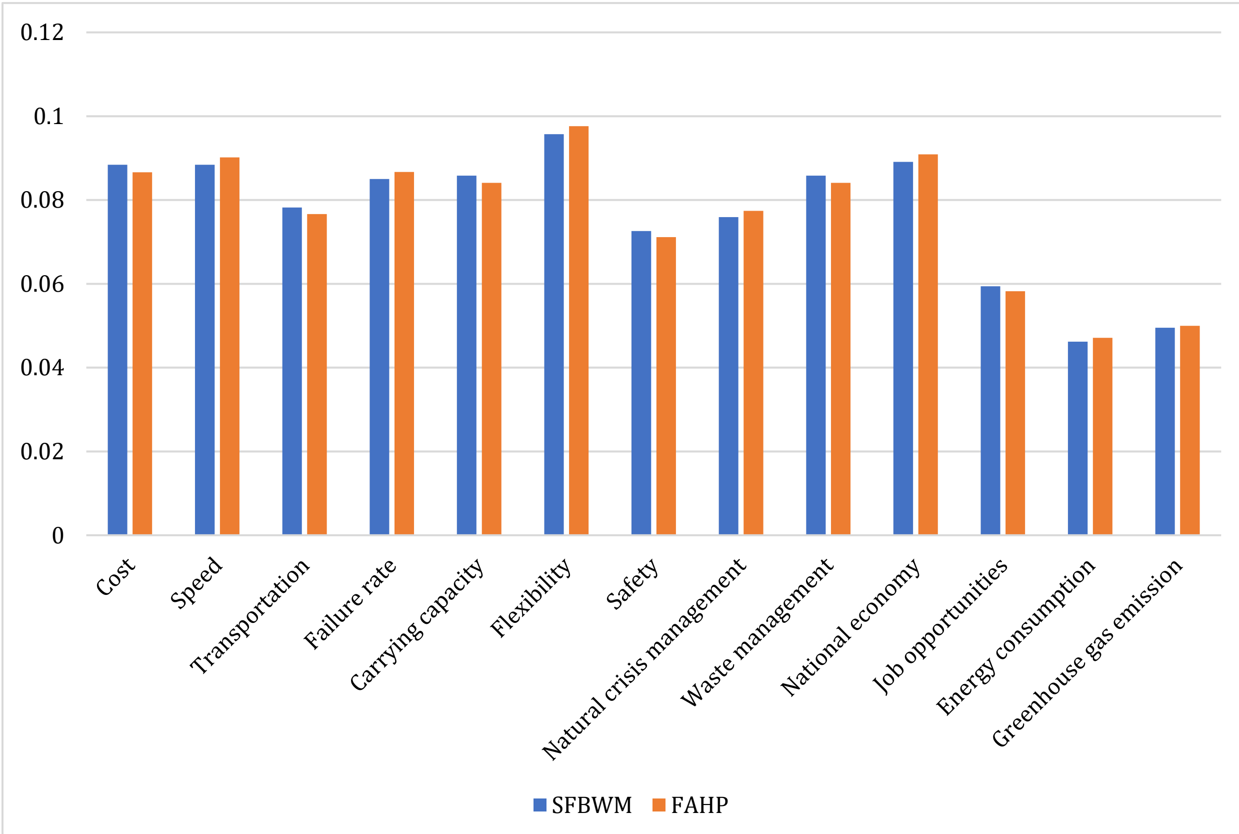


Figure 6. The CRs obtained by the SFBWM and FAHP

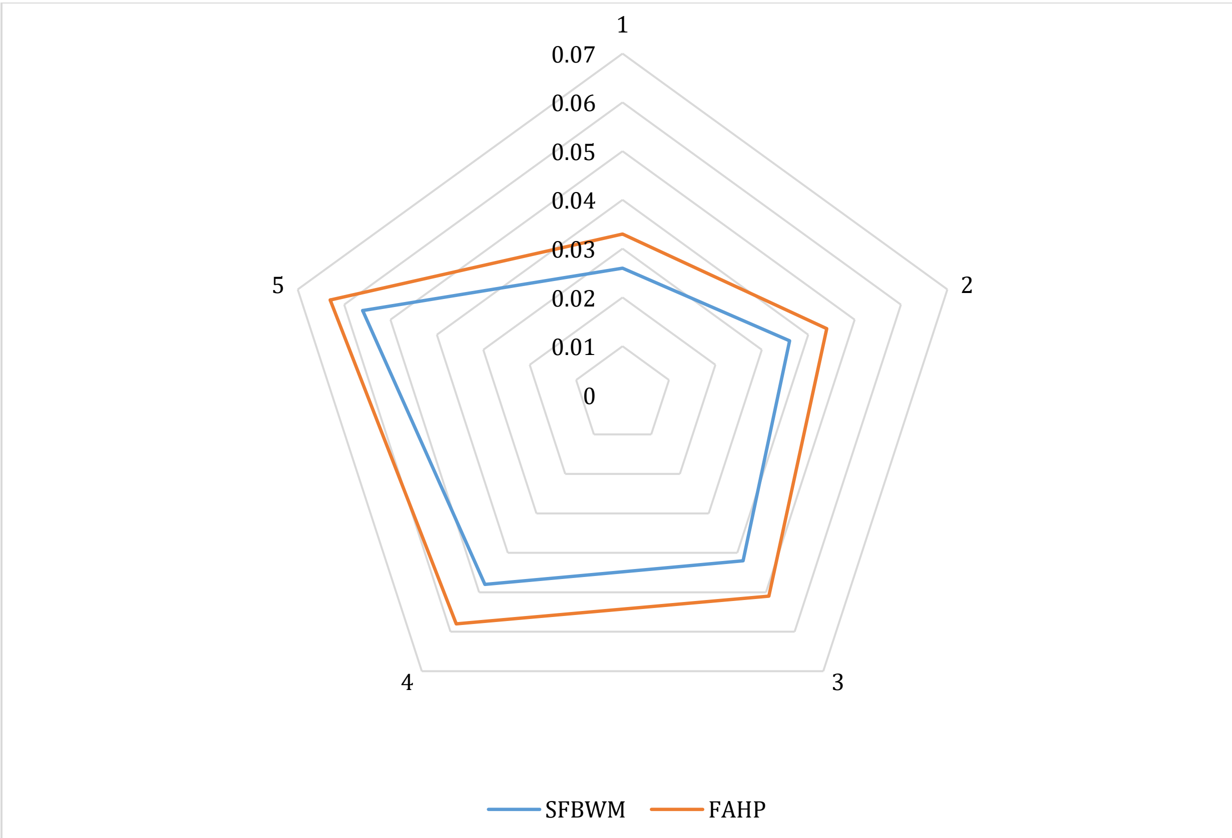
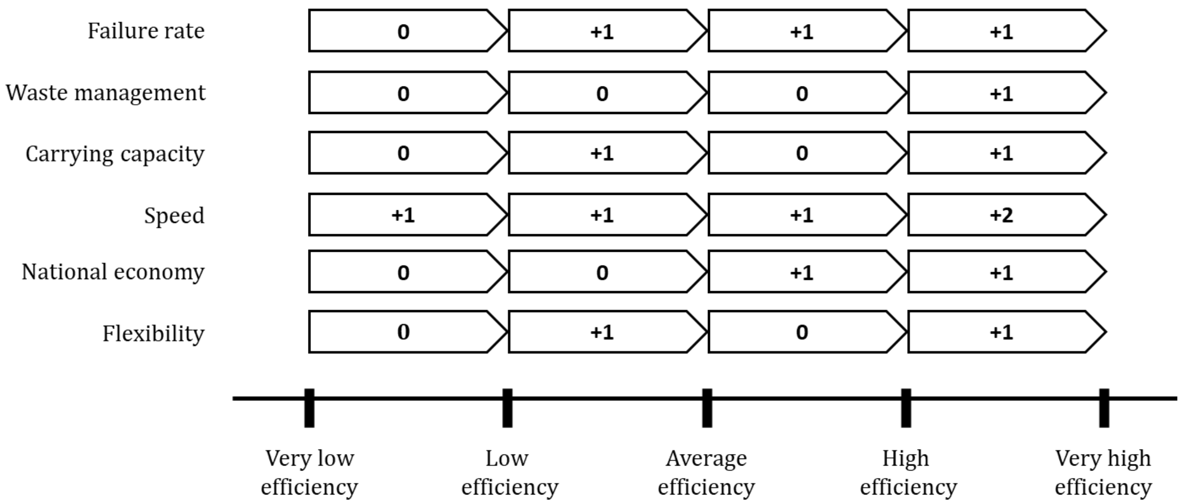


Table 16. Comparison of HWFIS with FBWM-FVIKOR and FAHP-FTOPSIS

Transportation mode	FSBWM-HWFIS	FBWM-FVIKOR	FAHP-FTOPSIS
Train	3	3	4
Truck	6	6	5
Mini truck	5	5	6
Airplane	1	1	1
Ship	2	2	2
Boat	4	4	3

Figure 7. Sensitivity analysis of important criteria on the efficiency of transportation modes



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