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Multi-Criteria Evaluation of Regional Logistics Sustainability: A Fuzzy AHP Analysis of the Mekong Delta Road Network

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Abstract. Road transport network plays the predominant role in the operations of domestic industry cum international logistics in Vietnam. Meanwhile, the economy of the Mekong Delta Region tends to constantly progress which requests more evaluations of transport infrastructure to adapt to the new macroeconomic environment. Applying the Fuzzy Analytic Hierarchy Process (Fuzzy AHP) method, this study evaluates the logistics performance of the road network from Ho Chi Minh City to the Mekong Delta Region based on 5 criteria and 19 sub-criteria: environment, accessibility, efficiency, travel cost, and safety - security. Survey data were collected by 30 logistics experts from regional enterprises. The outcomes reveal accessibility as the most critical criterion, while safety and security demonstrated the inverse pattern. The importance of the environment in regional logistics performance is relative, especially the light pollution. Moreover, port accessibility, servicing different transportation modes, minimizing any travel costs, and ensuring road signal systems are top priorities of road performance in each group of criteria. Nevertheless, by measuring in three approaches developed by Buckley, Chang, Ahmed & Killic, the ranks of sub-criteria in overall comparison differ significantly. On the basis of these key results, the study provides some managerial implications for policymakers and logistics stakeholders in regional logistics sustainability.

Keywords: Road Transport, Sustainability, Transport Sustainability, Performance evaluation, Fuzzy Analytic Hierarchy Process (Fuzzy AHP)

1. Introduction

The road transport network plays a predominant role in the domestic and international logistics operations in Vietnam. Meanwhile, the Mekong Delta Region has occupied the dominant position in the economic development of South Vietnam. There are 12 provinces in the Mekong Delta Region, including Long An, Ben Tre, Tien Giang, Vinh Long, Tra Vinh, Hau Giang, Dong Thap, Soc Trang, An Giang, Bac Lieu, Kien Giang, and Ca Mau. In 2022, five of them attained the top 20 leading PCI (Provincial Competitiveness Index) in the country (VCCI, 2022). This place contributed to 31.7% of Vietnam's agriculture GDP, particularly, 95% of rice and 60% of fish exported (Ministry of Agriculture and Rural Development of the Socialist Republic of Vietnam, 2022). According to The Annual Economic Report 2022 of the Mekong Delta Region held by the Vietnam Chamber of Commerce and Industry’s Branch in Can Tho (VCCI) and Fulbright School of Public Policy and Management (FSPPM), agriculture, as the incipient position in the economy of this place, experienced the considerable upward trend at 9.03% between 2015-2020, followed by the trivial increasing of industrial sector (4.39%) and service (3.82%) (VCCI, 2022). These rates are anticipated to soar in the next few years. Therefore, the fast-growing economy of the Mekong Delta Region necessitates meticulous evaluation of relevant road transport infrastructure to ensure environmental adaptation.

On account of the constant changes in macroscopic and microscopic demands, logistics performance is crucial to ensure sustainable development. The Council of Logistics Management explained that logistics relates to the strategies, approaches, and information for operating the flow and storage of products from the original stage to the consumption part (Lummus et al., 2001). The evaluation of transport-based projects is conducive to maximizing the advantageous information such as recommended initiatives, and societal benefits, and helping relevant parties make appropriate decisions at the right point in time (Bristow & Nellthorp, 2000). Having the equivalent perspective, Aldian & Taylor (2005) explained that logistics performance in transportation is the congregation of systematic stages and information that the experts or professionals in this field develop. Then, this knowledge is transformed to the decision-makers for analysis and utilization in practice. This process has made significant contributions and has been sharply carried out to service regional economic enhancement.

Moreover, in recent decades, the arguments for economic growth have not stopped at temporary targets, but have been expanded to a further norm, called the sustainable perspective. Based on the concept of Sustainable Development from the Brundtland Report (Burton, 1987) the Sustainable Transportation System targets the integration of socio-economic purposes in parallel with pro-environmental behavior which does not “sacrifice the ability of future generations to achieve the same goals”. Despite the business advantages, the spike of manufacturing and delivery in enterprises can be “paid” with the biological deterioration in cities (Heuer et al., 2003). In contrast, Moore & Pulidindi (2013) believed that citizens life quality referring to income threshold, and healthy neighborhoods could be improved due to the efficiency of the transportation system. Thus, it is inevitable that current research on logistics performance has to concentrate more on sustainable elements.

Scientifically, the logistics performance in transport has been exploited in various ways, from road networks to railway or marine routes, in many different nations (Weisbrod, 2008; Camargo Pérez et al., 2015; Özceylan et al., 2016; Yannis et al., 2020). The environmental standards are also emphasized in parallel with examining other economic advantages of the transport network (Awasthi & Chauhan, 2012; Sirikijpanichkul et al., 2017; Awasthi et al., 2018; Moslem et al., 2019; Kaewfak et al., 2021). Nevertheless, there are some research gaps in existing studies. A lack of papers is conducted to evaluate the standards of the current transport system in Vietnam or even the economic potential regions like the Mekong Delta Region. The relevant discussions about this place have mainly concentrated on the qualitative aspect. The application of multi-criteria decision-making-based approaches (MCDM) is limited. Moreover, not many previous papers examine the environmental standard in logistics performance. Environment sub-criteria have also remained unvaried and have not been expanded to some special environmental problems such as light pollution.

There have been many studies applied to the Fuzzy AHP method to exploit the predominant factors influencing logistic-based decisions. MCDM is considered one of the important research proclivities for logistics planning (besides survey-based approaches, simulation-based approaches, heuristics-based approaches, and cost-benefit analysis-based approaches)(Awasthi & Chauhan, 2012). In this kind of method, on the basis of some determined and weighted criteria, alternatives are evaluated to find out the one with the highest value. In particular, Fuzzy AHP is highly recommended since scholars can analyze the statistics of ensured and uncertain attitudes as well as provide appropriate selection for complex decisions (Sirikijpanichkul et al., 2017). Thus, on account of the above-proved benefits, this study is conducted with the support of the Fuzzy AHP method to clarify the most appropriate criteria for logistics of the Mekong Delta Region.

This study was conducted in order to fill the above-mentioned gaps. As an emerging country, Vietnam's road infrastructure necessitates more evaluation so as to balance between societal values and economic merits, leading to a sustainable economy. The hierarchy of 5 criteria - environment, accessibility, efficiency, travel cost, safety, and security which is divided into 19 sub-criteria is built. Moreover, utilizing the Fuzzy AHP Method, the priority weights are figured out, showing the rank of criteria and sub-criteria. This paper aims to clarify the level of importance of criteria compared to others in road logistics performance as well as determine the most important sub-criteria in each group. According to these outcomes, some planning and managerial suggestions are concluded.

The rest of the study is divided into the following parts: In Section 2, the Fuzzy AHP Method is shed light on, and the overview of relevant norms is presented. Section 3 is about the data and research methods applied in this study. The research findings demonstrating the priority weights in three different methods and meticulous outcomes are discussed in Section 4. Finally, the conclusion relating to some specific key points from the results is suggested in Section 5.

2. Literature Review

2.1. Fuzzy AHP Method

Fuzzy AHP is a quantitative method that is the integration of the AHP approach and Fuzzy Set Theory. AHP which was first introduced by Saaty (1980) is considered as the most popular tool in order to examine the logistics performance of transport networks. Meanwhile, the Fuzzy Set Theory was developed by Lotfi A. Zadeh in 1965 as the quantitative foundation to explore the vagueness of human awareness or decisions. This method is useful since the research issues relating to transportation are complicated with various targets or even conflicting objectives which can result in multiple decisions for specific projects (Shelton & Medina, 2010). Thus, basic quantifiable units cannot solve these problems. In comparison to the AHP method, Fuzzy AHP can solve the complexity and subjectiveness of judgments and result in more precise outcomes via calculating Triangular Fuzzy Numbers (TFNs) (Kaewfak et al., 2021). For many years, Fuzzy AHP has progressed and been applied to explore decision-making studies in supply chain management. On account of its prominent advantages compared to the AHP Method, the Fuzzy AHP Method was applied in this paper. The detailed steps of the Fuzzy AHP Method will be demonstrated in the following sections.

2.2. Accessibility (AC)

In logistics, accessibility or connectivity was defined as the level of ability to approach the warehouse and final customer's positions (Awasthi & Chauhan, 2012), to connect the routes from the origins to the last stage through the series of motorized transport infrastructure (Shelton & Medina, 2010). They also asserted that the enhancement of these criteria can be demonstrated by decreasing roadway congestion, supplying more direction alternatives, and ensuring the paths to public transit. Having a similar opinion, in Targa et al.'s paper (2005), the approachability to intermodal terminals was also emphasized to improve the accessibility of road networks with industrial efficiency. This feature is extremely important to evaluate the logistics network in the Mekong Delta since this region has a variety of small and big river systems. The integration of multi-transport, particularly, road and marine systems, would be fostered. Furthermore, some sub-criteria including the total length of the highway, proximity to transit places (ports, railway, airports, border gates) (Özceylan et al., 2016) or ease of access and transfer (Sirikijpanichkul et al., 2017) which are considered primary elements revealing for logistics connectivity were also analyzed. In this study, accessibility (AC) is demonstrated through the number of junctions (AC1), the number of roads (AC2), providing alternative routes (AC3), port accessibility (AC4), and the length of way (AC5).

2.3. Efficiency (EF)

The efficiency of road transport can be evaluated with many different features, depending on each location. Awasthi & Chauhan (2012) explained this criterion as the success of distribution operated by logistical expertise, showing through the downward trend of distance, delivery time, and the increasing capacity per trip. Yannis et al. (2020) congregated the feature of transport system efficiency in their study, including the maximum mitigation of time, congestion, and construction period in parallel with fostering time-based trust, service convenience, transport integration, transport network capacity, and passenger/freight movements. In general, these studies especially emphasized time efficiency and capacity maximization are considered as one of the priorities to evaluate transport performance. Furthermore, the efficiency of the transport system is also revealed by the connectivity to multimodal transport (Awasthi et al., 2018). Moslem et al., (2019) considered the timescale of a determined form of transport and the speed of delivery to examine the efficiency of transport. Speed improvement and multi-functional ability for different transport were also believed to the important features for transport efficiency. On account of these above-mentioned suggestions, the efficiency (EF) in this paper is divided into speed improvement (EF1), time efficiency (EF2), maximizing transport network capacity (EF3), and servicing for different modes of transportation (EF4).

2.4. Travel Cost (TC)

According to Camargo Pérez et al. (2015), travel cost pertains to the monetary resources such as the expense of implementation, infrastructure investment, taxes, operational costs, maintenance costs, and fuel costs. Revenues, investment costs, operating costs (labor, maintenance, fuel costs,… for the transport operator), and travel costs (ticket price, trip cost for the customer) were utilized in Awasthi et al.'s paper (2018) to evaluate urban mobility projects in Luxembourg. Sirikijpanichkul et al. (2017) examined the transit system selection in Bangkok, Thailand with the criteria of capital cost (million baht per kilometer), and operating and maintenance cost (baht per revenue hour – transit unit). This research had a common attitude toward operating cost as the paramount factor for logistics performance. Moreover, the measures of effectiveness (MOE) in Korea developed by Tabucanon & Lee (1995), travel cost was not only revealed with vehicle operating costs but also applied with tolls and fares, parking expense. This research highlighted the contribution of tolls, fares, and parking expenses, which are also heavy costs for enterprises in the Mekong Delta Region. Thus, the criteria of travel cost (TC) is indicated through minimizing vehicle operating cost (TC1), minimizing tolls and fares (TC2), and minimizing parking cost (TC3).

2.5. Safe and security (SS)

Safety and Security are important criteria of logistics performance. These relate to the situation of congestion during the distribution process (Awasthi & Chauhan, 2012) or at the peak times which intervene the traffic movements and boost the likelihood of non-recurring incidents (Weisbrod et al., 2003). Congestion is one of the most prominent problems in developing countries such as Vietnam. In the Mekong Delta Region, on account of dense popularity, high transport volume, and poor road infrastructure, congestions still happen daily without any efficient solutions. Furthermore, Shelton & Medina (2010) asserted that not only the congestion-related mitigation but also the decrease in traffic crashes per mile implied as the prerequisite standard for road network systems. Other features, such as minimization of fatalities, injuries, or traffic violations, figures for accidents, and geometric conditions, were also emphasized (Yannis et al., 2020). Transport safety is also demonstrated through the standards relating to the small infrastructure on the roads such as the number of traffic enforcement cameras (Kerimov et al., 2017). The lack of papers has structured this feature as a criterion of logistics performance despite their paramount roles in the whole transport operations. Thus, considering a small infrastructure for transport and signal systems is one of the prominent contributions of this paper compared to other research. To examine the criteria of safety and security (SS), this study has utilized three sub-criteria: congestion reduction (SS1), the reduction of vehicle crashes (SS2), and the performance of road signal systems (SS3).

2.6. Environment (EN)

Environmental criteria play the prerequisite role in evaluating the sustainable logistics performance of road networks. The consequences of distribution on the environment relate to the generation of air pollution or noise (Awasthi & Chauhan, 2012). Transportation infrastructure projects combined with environmental features are advantageous. They can protect the preservation of natural resources as well as community characteristics such as culture (Shelton & Medina, 2010). In more detail, Camargo Pérez et al. (2015) revealed in their study that the mitigation of noise, air, and energy (such as carbon emission, and fuel consumption) of highway systems was crucial for the purpose of choosing efficient routes. Yannis et al. (2020) also recommended the minimization of some elements as the criteria of environment for a transport system, including air, noise, and water pollution, visual consequences, land use fragmentation, natural biology, and fuel usage. Air, noise pollution, and fuel waste are the most common standards for road network evaluation. Nevertheless, there has been a limitation in exploiting light pollution which is one of the macroscopic predicaments stemming from poor road infrastructure. Thus, to evaluate the environmental criteria (EN), this paper not only emphasizes the reduction of air pollution (EN1), reduction of noise (EN2), and reduction in consumption of fuel (EN3) but also clarifies the reduction of light pollution (EN4).

3. Research methodology

3.1. Fuzzy set theory

The fuzzy set theory was introduced originally by Zadeh (1965), which is an expansion of classical notation set theory (Dubois & Prade, 1980). Assuming that A is a set. In the classical set theory, also called Crisp Set, every single element "x" in the universe of discourse "X" definitely belongs to A or definitely does not belong to A with the following Equation:

$$\forall\, x \in U, \mu_A(x) = \begin{Bmatrix} 1\ if\ x \in A \\ 0\ if\ x \notin A \end{Bmatrix} \ (1)$$

It is obvious that the membership function μ_A will define the crisps subset A on the universe set "X" where μ_A just accepts values in the set $\{0,1\}$. Nevertheless, human judgment is sometimes imprecision and vague because of the uncertainty of the information (Zadeh, 1965). Therefore, to handle this issue, a fuzzy set theory is established. The degree of uncertainty in the membership function of fuzzy set theory is able to be clarified so as to accept a more nuanced approach to reasoning (Gupta et al., 2023). Each object of a membership grade is assigned through the membership function, expressing a value ranging from 0 to 1 (Gupta et al., 2023; Kınay & Tezel, 2021).

The function of the fuzzy set theory begins with the following Definition:

Definition 1: Let "X" be a universe of discourse. A fuzzy set $\tilde{A}$ on X is identified by the membership function μ_A. Each element "x" of the set "X" is assigned as one value $\mu_A(x)$ where $0 \le \mu_A(x) \le 1$, referring to the level at which each element "x" belongs to the fuzzy set $\tilde{A}$. In other words, a fuzzy set $\tilde{A}$ on the universe of discourse X can be defined by:

$$\mu_A: X \to [0,1] \ (2)$$

Definition 2: There are two gatherings of fuzzy numbers in this fuzzy set, including Triangular Fuzzy

Number (TFN) and Trapezoidal Fuzzy Number (TraFN) (Liu et al., 2020). The Triangular Fuzzy Number has three real numbers, including l, m, u where $l < m < u$. Let $\tilde{A} = (l, m, u)$, the membership function of TFN is (Kınay & Tezel, 2021):

$$u_{\tilde{A}}(x) = \begin{cases} \frac{(x-l)}{(m-l)}, if\ l < x < m \\ 1, if\ x = m \\ \frac{(u-x)}{(u-m)}, if\ m < x < u \\ 0, otherwise \end{cases} \quad (3)$$

Definition 3: The support of a fuzzy number $\tilde{A}$ is a crisp set of all $x \in U$ and $u_{\tilde{A}} > 0$.

$$supp(\tilde{A}) = \{x | u_{\tilde{A}}(x) > 0\} \ (4)$$

Definition 4: The core of a fuzzy number $\tilde{A}$, is a crisp set of all $x \in U$ and $u_{\tilde{A}} = 1$

$$core(\tilde{A}) = \{x | u_{\tilde{A}}(x) = 1\} \ (5)$$

Definition 5: The height of a fuzzy number $\tilde{A}$ is the supremum of $u_{\tilde{A}}$ over U (Kınay & Tezel, 2021):

$$h(\tilde{A}) = \underset{x \in X}{supp}\, u_{\tilde{A}}(x) \ (6)$$

Definition 6: Let $\tilde{A} = (l_1, m_1, u_1)$, and $\tilde{B} = (l_2, m_2, u_2)$ be triangular fuzzy numbers. Thus, we have the following fuzzy Equations:

The summary of $\tilde{A}$ and $\tilde{B}$ is defined by: $\tilde{A} \oplus \tilde{B} = (l_1 + l_2,\ m_1 + m_2, u_1 + u_2)$ (7)

The subtraction of $\tilde{A}$ and $\tilde{B}$ is defined by: $\tilde{A} \ominus \tilde{B} = (l_1 - l_2,\ m_1 - m_2, u_1 - u_2)$ (8)

The multiplication of $\tilde{A}$ and $\tilde{B}$ is defined by: $\tilde{A} \otimes \tilde{B} = (l_1 * l_2,\ m_1 * m_2, u_1 * u_2)$ (9)

The division of $\tilde{A}$ and $\tilde{B}$ is defined by: $\tilde{A} \oslash \tilde{B} = (l_1/l_2,\ m_1/m_2, u_1/u_2)$ (10)

The inverse of $\tilde{A}\ or\ \tilde{B}$ is defined by: $(l, m, u)^{-1} = \left(\frac{1}{u}, \frac{1}{l}, \frac{1}{m}\right)$ (11)

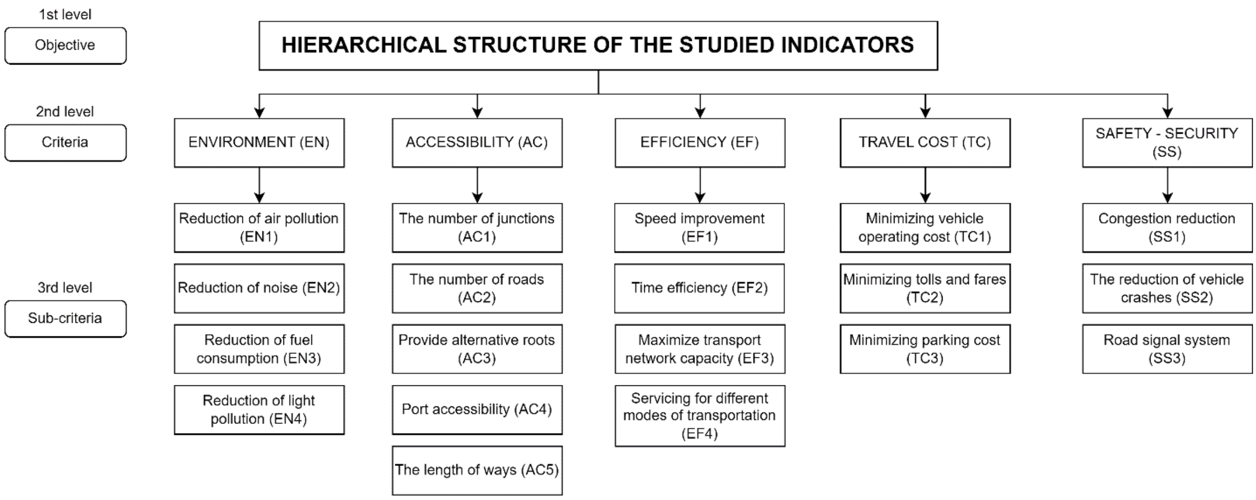

Fig 1: The hierarchical structure of the study

3.2. Hierarchical structure of the research and questionnaire design

This model is constructed based on five indicators, including EN, AC, EF, TC, and SS. EN is designed by four sub-criteria, while AC and EF are classified into 5 and 4 factors, particularly. Both TC and SS are divided into three sub-criteria. These standards were chosen selectively by referring to the previous studies. The rationale for each factor is discussed in **Section 2**.

The sampling process is categorized into two periods. In the initial stage, there were 10 experts examining the precision of certain criteria. After that, the official survey with 2 sections was completed and sent to 30 experts. The premise of the given questionnaire included ethical commitment. The participant's personal information is ensured to be confidential. The responses were just utilized for scholarly objectives. In Section 1, the participant's personal information was collected, including the age, gender, working experience, education level, job position, and types of businesses. Section 2 focused on evaluating the importance of criteria and sub-criteria which was designed as a 9-point scale developed by Saaty in 1980. The final data was analyzed with Microsoft Excel software.

The statistics for the research task were collected from questionnaire surveys done by 30 trustworthy experts in the fields of logistics, development economics, and transport infrastructure techniques. The proportion of experts aged 46 – 50 occupied the incipient position with 23% while the percentages for 51-55 and 56-60 groups obtained similar results at 20%. The under-35-age experts accounted for 17%, followed by those aged 36 – 40 at 13%. The smallest representation was the 41 – 45 age group with 7% of the total gatherings. There were 22 male participants (73%) and 8 female experts (27%). Besides, 6 – 10 years and 11 – 15 years of working experience attained the same percentage at 40%. Others had above 25 years (17%) or 21-25 years of working experience (3%). Moreover, 53% of experts had had bachelor's degrees when 43% of others had completed master's systems and 3% of participants did not have graduate or postgraduate degrees. In terms of working positions, 12 Deputy Managers and 12 Deputy Directors represented 40% of each, while the figure for Department Managers contributed 6 experts (at 20%). Generally, there are 7 representatives of Sole Proprietorships (23%), 8 for Limited Liability Companies (27%), and 8 for Joint Stock Companies (27%). State-owned enterprises made up 20% with 6 experts while the figure for Partnerships was just represented by 1 person at 3%. These companies are established and operated in the Mekong Delta Region. The results are described in **Table 1.**

Table 1: The descriptive analysis of respondents

Gatherings		Frequency	Proportion
Age group	Under 35	5	17%
	36 – 40	4	13%
	41 – 45	2	7%
	46 – 50	7	23%
	51 – 55	6	20%
	56 – 60	6	20%
	Above 60	0	0%
Gender	Male	22	73%
	Female	8	27%
Working experience of years	6 – 10 years	12	40%
	11 – 15 years	12	40%
	16 – 20 years	0	0%
	21 – 25 years	1	3%
	Above 25 years	5	17%
Academic degree	Ph.D.	0	0%
	Master	13	43%
	Bachelor	16	53%
	College	0	0%
	Others	1	3%
Position in the company	President/Vice president	0	0%
	Manager	0	0%
	Deputy manager	12	40%
	Head of Department	6	20%
	Deputy head of Department	12	40%
	Others	0	0%
Types of enterprises	Sole proprietorship	7	23%
	Liability Limited Company	8	27%
	Joint Stock Company	8	27%
	Partnerships	1	3%
	Government company	6	20%
	Others	0	0%

Source: The authors' calculation

3.3. Flowchart structure of the research

Step 1: Determine the objective of the decision-making problem. This study is based on the fuzzy AHP to define the optimal road network criteria under human judgment uncertainty.

Step 2: Construct the hierarchical structure with the objective at the top level, criteria at the second level, and sub-criteria at the third level.

Step 3: Establish the pairwise comparison matrices between factors.

Step 4: The given matrices have been converted into fuzzy comparison matrices with the linguistics converting scale. The fuzzy numbers have also been transformed into triangular fuzzy numbers. The linguistics converting scale is detailed in **Table 2.**

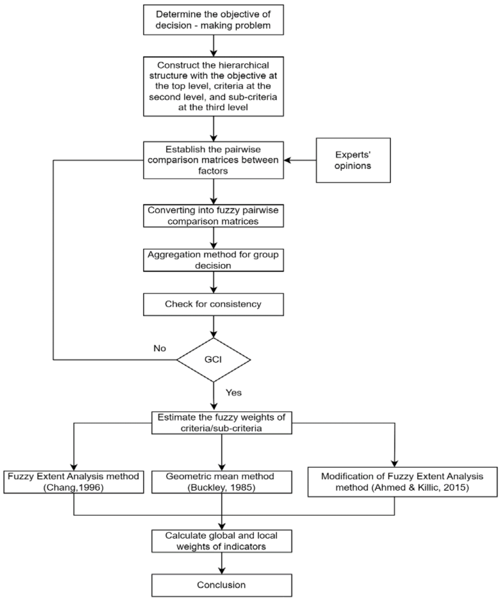

Fig 2: Flowchart of the study

Table 2: Linguistic importance scale

Linguistic importance scale	Fuzzy numbers	Triangular fuzzy number	The inverse of triangular fuzzy number
Equally important	$\tilde{1}$	(1,1,1)	(1,1,1)
Moderate important	$\tilde{3}$	(2,3,4)	(1/4,1/3,1/2)
Strong important	$\tilde{5}$	(4,5,6)	(1/6,1/5,1/4)
Very strong important	$\tilde{7}$	(6,7,8)	(1/8,1/7,1/6)
Extremely strong important	$\tilde{9}$	(9,9,9)	(1/9,1/9,1/9)
Intermediate	$\tilde{2}$	(1,2,3)	(1/3,1/2,1)
	$\tilde{4}$	(3,4,5)	(1/5,1/4,1/3)
	$\tilde{6}$	(5,6,7)	(1/7,1/6,1/5)
	$\tilde{8}$	(7,8,9)	(1/9,1/8,1/7)

Source: Zadeh (1965)

Step 5: Aggregation method for group decision. The fuzzy pairwise comparison matrices are summarized via many methods (Liu et al., 2020). In general, the geomean method and the max-min method are the two most popular methods (Buckley, 1985; Meixner, 2009). In this study, the Geomean method will be applied to summarize the opinions. Let $\tilde{A}_{ij} = (l_{ij}, m_{ij}, u_{ij})$ and $l_{ij} < m_{ij} < u_{ij}$be a Triangular Fuzzy Number. The Equation to aggregate for group decision is constructed by the following formula:

$$\tilde{A}_{ij} = (l_{ij}, m_{ij}, u_{ij}) = \left(\prod_{t=1}^{q} \tilde{A}_{ij}^{(t)}\right)^{\frac{1}{q}} = \left(\left(\prod_{t=1}^{q} l_{ij}^{(t)}\right)^{\frac{1}{q}}, \left(\prod_{t=1}^{q} m_{ij}^{(t)}\right)^{\frac{1}{q}}, \left(\prod_{t=1}^{q} u_{ij}^{(t)}\right)^{\frac{1}{q}}\right) \text{ where t=1, 2, 3,…,n.} \quad (14)$$

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Step 6: Check the consistency of fuzzy pairwise comparison matrices

The final step in this research is checking the consistency of the fuzzy matrix. This step is performed on the basis of the geometric consistency index as follows (Z.-J. Wang & Lin, 2017):

$$GCI(\tilde{A}) = \begin{cases} \frac{2}{(n-1)(n-2)} \times \sum_{i<j} \left(\log a_{ij}^{m} - \frac{1}{n}\sum_{k=1}^{n}\left(\log a_{ik}^{m} + \log a_{kj}^{m}\right)\right)^2 , \\ \frac{1}{2(n-1)(n-2)} \times \sum_{i<j} \left(\log a_{ij}^{l} + \log a_{ij}^{u} - \frac{1}{n}\sum_{k=1}^{n}\left(\log a_{ik}^{l} + \log a_{ik}^{u} + \log a_{kj}^{l} + \log a_{kj}^{u}\right)\right)^2 \end{cases} \quad (15)$$

The acceptable thresholds of the GCI index comply with the number of criteria in the fuzzy pairwise comparison matrices, which follow as:

$$GCI = \begin{cases} 0.3147 \ if \ n = 3 \\ 0.3563 \ if \ n = 4 \ (16) \\ 0.3700 \ if \ n \geq 5 \end{cases}$$

In case the computed GCI is lower than the thresholds of GCI, it can be concluded that the fuzzy pairwise comparison matrix is consistent.

Step 7: Estimate the fuzzy weights of criteria and sub-criteria.

As mentioned above, the priority weights of criteria and sub-criteria are estimated on the basis of three following methods:

Firstly, the geometric mean method by Buckley (1985) is estimated by the following Equation:

(i) The geometric mean of triangular fuzzy numbers of each factor is calculated by:

$$\tilde{r}_i = (\tilde{a}_{i1} * \tilde{a}_{i2} * \tilde{a}_{i3} * … * \tilde{a}_{in})^{1/n}, \ (17)$$

$$\text{where } \tilde{l}_{ij} = (\prod_{j=1}^{n} l_{ij})^{1/n}, \tilde{m}_{ij} = (\prod_{j=1}^{n} m_{ij})^{1/n}, \tilde{u}_{ij} = (\prod_{j=1}^{n} u_{ij})^{1/n} \ (18)$$

(ii) The fuzzy weights can be defined by:

$$\tilde{w}_i = \left(\tilde{l}_{wi}, \tilde{m}_{wi}, \ \tilde{r}_{wi}\right) = \tilde{r}_i \otimes (\tilde{r}_1 \oplus \tilde{r}_2 \oplus … \oplus \tilde{r}_n)^{-1} \ (19)$$

(iii) Defuzzification of fuzzy weights. This research applied the centroid defuzzification method (COA) to estimate defuzzied weights. This method will be portrayed specifically in Section 2 with the Equations (27), and (28).

(iv) Normalization of fuzzy weights. The authors applied this Equation to compute the normalized weight:

$$w = \frac{\tilde{w}_i}{\sum \tilde{w}_i} \ (20)$$

Secondly, the fuzzy extent analysis method proposed by (Chang, 1996). This method is estimated on the basis of the following steps:

(i) Computing the value of fuzzy synthetic extent with respect to the i[th] object as follows:

$$S_i = \sum_{j=1}^{n} \tilde{a}_{ij} \otimes \left[\sum_{i=1}^{n}\sum_{j=1}^{n} \tilde{a}_{ij}\right]^{-1} \quad (21)$$

$$\text{Where } \sum_{j=1}^{n} \tilde{a}_{ij} = \left(\sum_{j=1}^{n} l_j, \sum_{j=1}^{n} m_j, \sum_{j=1}^{n} u_j\right) \ (22)$$

(ii) Calculating the degree of possibility of S_i utilizing the Equation:

$$V(M_2 \geq M_1) = sup \ y \geq x \ \left[min\left(\mu_{M_{1(x)}}, \mu_{M_{2(y)}}\right)\right] = hgt(M_1 \cap M_2)$$

$$= \begin{cases} 1, if \ m_2 \geq m_1 \\ 0, if \ l_1 \geq u_2 \\ \frac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)} \end{cases} \quad (23)$$

(iii) Calculating the degree of possibility for a convex fuzzy number to be higher than k convex fuzzy number as follows:

$$d'(A_i) = V(S \geq S_1, S_2, …, S_k) = min(S \geq S_i), i = 1, 2, 3, …, k \ (24)$$

Where $d'(A_i) = \ min(S_i \geq S_k), for \ k = 1,2,3, … , n, k \neq i$, and $A_i(i = 1,2,3, … . , n)$ are elements.

(iv) Estimating the weight value and normalized them as follows:

$$\text{We have: } W' = \left(d'(A_1), d'(A_2), d'(A_3), \dots, d'(A_n)\right)^T (25)$$

The normalized weight vector is determined by:

$$\mathrm{W} = \left(d(A_1), d(A_2), d(A_3), \dots, d(A_n)\right)^T (26).$$

Thirdly, the modification to fuzzy extent analysis was developed by Ahmed and Kilic (2015). This method is to enhance the fuzzy extent analysis method of Chang (1996) by solving the null weights in Chang's method (Kınay & Tezel, 2021; Lima-Junior & Carpinetti, 2020). The modified fuzzy extent analysis is also called the Fuzzy Row Sum Method which is the combination of Fuzzy Extent Analysis (FEA) with a centroid defuzzification method (Ahmed & Kilic, 2019). This method is followed by two sections. The first section is defined on the basis of Chang's method in which the row sums of the matrices are estimated and then normalized. The second section is performed by applying the centroid defuzzification method which is proposed by Ross (1995) instead of the degree of possibility step of Chang (1996) (Ahmed & Kilic, 2015, 2019). On the basis of the above instructions, this method is defined based on the following formulas:

i) The estimation and normalization of the row sums of the matrices: This step is aligned with the first step of Chang's method by applying the Equations (21), and (22).

ii) Centroid defuzzification method to calculate the priority weights.

The centroid defuzzification method, also called the center of the area (COA) or center of gravity (COG) is one of the most trustworthy and popular defuzzification methods (Ross, 2009). The equation of the COA method is as:

$$x^* = \frac{\int \mu(x)xdx}{\int \mu(x)dx} \quad (27)$$

On the basis of the utilization of the TFNs, this Equation can be modified into the following simple equation which is utilized in many research (Liu et al., 2020; Y.-M. Wang et al., 2006):

$$x^* = \frac{l + m + u}{3} \quad (28)$$

Where l, m, u are TFNs.

(iii) Normalized weight is estimated by Equation (20).

Step 8: Calculate the local and global weights.

The local weight of sub-criteria is the normalized weight computed by the above Equations. The global weight of sub-criteria is computed by the following formula (Gupta et al., 2023):

Global weight of sub-criteria 1 = Local weight of sub-criteria 1 * Relative importance of criteria (29)

4. Research findings

4.1. Numerical calculation for the priority weight of road network factors

This section details how the priority weights of fuzzy pairwise comparison matrices are estimated, in which the fuzzy pairwise comparison matrix of the criteria in **Table 3** is used to be an example in this calculation.

Table 3: Fuzzy pairwise comparison matrice for the criteria

	EN	AC	EF	TC	SS
EN	**(1.0000,1.0000,1.0000)**	(0.8440, 0.9585, 1.8021)	(0.9383, 1.1448, 1.3741)	(0.8073, 0.9557, 1.1074)	(1.0079, 1.2040, 1.4310)
AC	(0.9241, 1.0433, 1.1848)	**(1.0000,1.0000,1.0000)**	(1.0057, 1.1607, 1.3069)	(0.7725, 0.9291, 1.1074)	(1.0574, 1.2707, 1.5190)
EF	(0.7277, 0.8735, 1.0657)	(0.7652, 0.8615, 0.9944)	**(1.0000,1.0000,1.0000)**	(0.8789, 1.0400, 1.2242)	(0.9548, 1.1190, 1.3149)
TC	(0.9030, 1.0463, 1.2387)	(0.9030, 1.0763, 1.2944)	(0.8169, 0.9616, 1.1377)	**(1.0000,1.0000,1.0000)**	(1.1643, 1.2959, 1.4142)
SS	(0.6988, 0.8305, 0.9922)	(0.6583, 0.7870, 0.9457)	(0.7605, 0.8937, 1.0473)	(0.7071, 0.7717, 0.8589)	**(1.0000,1.0000,1.0000)**
GCI=0.0013 < 0.3700 → Consistency					

Source: The authors' calculation

Firstly, checking for consistency of fuzzy pairwise comparison matrice. On the basis of the fuzzy pairwise comparison matrix of criteria, the consistency is calculated through Equation (15) with the following results:

$$GCI(\tilde{A}) = \{0.0013, 0{,}0010\} = 0.0013$$

This finding is lower than the threshold $n \geq 5$ $with\ the\ value$ 0.3700. Therefore, it can be concluded that this matrix of criteria is consistent.

Secondly, computing the weight values of the matrices.

- **With respect to the geometrical method of Buckley (1985),** in the first step, the geometrical mean value $\tilde{r}_i$ will be calculated as follows:

$\tilde{r}_1 = (\tilde{a}_{11} * \tilde{a}_{12} * \tilde{a}_{13} * \tilde{a}_{14} * \tilde{a}_{15})^{1/5}$
$=(4.5975^{\,1/5}, 5.2631^{\,1/5}, 5.9946^{\,1/5})$
$= (0.9159, 1.0478, 1.1870)$

$\tilde{r}_2 = (\tilde{a}_{21} * \tilde{a}_{22} * \tilde{a}_{23} * \tilde{a}_{24} * \tilde{a}_{25})^{1/5}$
$= (0.9464, 1.0741, 1.2110)$

$\tilde{r}_3 = (\tilde{a}_{31} * \tilde{a}_{32} * \tilde{a}_{33} * \tilde{a}_{34} * \tilde{a}_{35})^{1/5}$
$= (0.8589, 0.9738, 1.1127)$

$\tilde{r}_4 = (\tilde{a}_{41} * \tilde{a}_{42} * \tilde{a}_{43} * \tilde{a}_{44} * \tilde{a}_{45})^{1/5}$
$= (0.9504, 1.0701, 1.2087)$

$\tilde{r}_5 = (\tilde{a}_{51} * \tilde{a}_{52} * \tilde{a}_{53} * \tilde{a}_{54} * \tilde{a}_{55})^{1/5}$
$= (0.7563, 0.8527, 0.9667)$

In the second step, the fuzzy weight of the matrices can be estimated as follows:

$$\tilde{w}_1 = \tilde{r}_1 \otimes (\tilde{r}_1 \oplus \tilde{r}_2 \oplus \tilde{r}_3 \oplus \tilde{r}_4 \oplus \tilde{r}_5)^{-1}$$

$$= \left(\frac{0.9159}{1.1870 + 1.2110 + 1.1127 + 1.2087 + 0.9667}, \frac{1.0478}{1.0478 + 1.0741 + 0.9738 + 1.0701 + 0.8527}, \frac{1.1870}{0.9159 + 0.9464 + 0.8589 + 0.9504 + 0.7563}\right)$$

$$= (0.1611, 0.2088, 0.2681)$$

$\tilde{w}_2 = \tilde{r}_2 \otimes (\tilde{r}_1 \oplus \tilde{r}_2 \oplus \tilde{r}_3 \oplus \tilde{r}_4 \oplus \tilde{r}_5)^{-1}$
$= \left(\frac{0.9464}{5.6861}, \frac{1.0741}{5.0185}, \frac{1.2110}{4.4278}\right)$
$= (0.1664, 0.2140, 0.2735)$

$\tilde{w}_3 = \tilde{r}_3 \otimes (\tilde{r}_1 \oplus \tilde{r}_2 \oplus \tilde{r}_3 \oplus \tilde{r}_4 \oplus \tilde{r}_5)^{-1}$
$= \left(\frac{0.8589}{5.6861}, \frac{0.9738}{5.0185}, \frac{1.1127}{4.4278}\right)$
$= (0.1510, 0.1940, 0.2513)$

$\tilde{w}_4 = \tilde{r}_4 \otimes (\tilde{r}_1 \oplus \tilde{r}_2 \oplus \tilde{r}_3 \oplus \tilde{r}_4 \oplus \tilde{r}_5)^{-1}$
$= \left(\frac{0.9504}{5.6861}, \frac{1.0701}{5.0185}, \frac{1.2087}{4.4278}\right)$
$= (0.1672, 0.2132, 0.2730)$

$\tilde{w}_5 = \tilde{r}_5 \otimes (\tilde{r}_1 \oplus \tilde{r}_2 \oplus \tilde{r}_3 \oplus \tilde{r}_4 \oplus \tilde{r}_5)^{-1}$
$= \left(\frac{0.7563}{5.6861}, \frac{0.8527}{5.0185}, \frac{0.9667}{4.4278}\right)$
$= (0.1330, 0.1699, 0.2183)$

In the third step, the defuzzied weights of criteria are computed as follows:

$W_1^* = \frac{0.1611 + 0.2088 + 0.2681}{3} = 0.2126$

$W_2^* = \frac{0.1664 + 0.2140 + 0.2735}{3} = 0.2180$

$W_3^* = \frac{0.1510 + 0.1940 + 0.2513}{3} = 0.1988$

$W_4^* = \frac{0.1672 + 0.2132 + 0.2730}{3} = 0.2178$

$W_5^* = \frac{0.1330 + 0.1699 + 0.2183}{3} = 0.1737$

In the fourth step, the normalized weights will be calculated as below:

$$W = (0.2083, 0.2135, 0.1947, 0.2133, 0.1702)^T$$

- **In regard to the Fuzzy Extent Analysis method by Chang (1996)**

In the first step, the row sums of the fuzzy pairwise comparison matrices will be calculated and normalized as below:

$$S_i = \sum_{j=1}^{n} \tilde{a}_{ij} \otimes \left[\sum_{i=1}^{n}\sum_{j=1}^{n} \tilde{a}_{ij}\right]^{-1}$$

We have $\sum_{j=1}^{5} \tilde{a}_{1j}$ = (1.000, 1.000, 1.0000) + (0.8440, 0.9585, 1.0821) + (0.9383, 1.1448, 1.3741) + (0.8073, 0.9557, 1.1074) + (1.0079, 1.2040, 1.4310) = (4.5975, 5.2631, 5.9946)

$$\sum_{j=1}^{5} \tilde{a}_{2j} = (4.7597, 5.4039, 6.1182)$$

$$\sum_{j=1}^{5} \tilde{a}_{3j} = (4.3267, 4.8940, 5.5992)$$

$$\sum_{j=1}^{5} \tilde{a}_{4j} = (4.7872, 5.3800, 6.0851)$$

$$\sum_{j=1}^{5} \tilde{a}_{5j} = (3.8247, 4.2828, 4.8441)$$

Then, to calculate $\left[\sum_{i=1}^{n}\sum_{j=1}^{n}\tilde{a}_{ij}\right]^{-1}$, it can be seen that

$$\left[\sum_{i=1}^{n}\sum_{j=1}^{n}\tilde{a}_{ij}\right]^{-1} = \left(\frac{1}{5.9946+6.1182+5.5992+6.0851+4.8441}, \frac{1}{5.2631+5.4039+4.8940+5.3800+4.2828}, \frac{1}{4.5975+4.7597+4.3267+4.7872+3.8247}\right)$$
$$= (0.0349, 0.0396, 0.0449)$$

Consequently, the values of fuzzy synthetic extent are computed as follows:

$$S_1 = (4.5975, 5.2631, 5.9946) \otimes (0.0349, 0.0396, 0.0449) = (0.1605, 0.2087, 0.2689)$$
$$S_2 = (4.7597, 5.4039, 6.1182) \otimes (0.0349, 0.0396, 0.0449) = (0.1662, 0.2142, 0.2744)$$
$$S_3 = (4.3267, 4.8940, 5.5992) \otimes (0.0349, 0.0396, 0.0449) = (0.1511, 0.1940, 0.2511)$$
$$S_4 = (4.7872, 5.3800, 6.0851) \otimes (0.0349, 0.0396, 0.0449) = (0.1671, 0.2133, 0.2729)$$
$$S_5 = (3.8247, 4.2828, 4.8441) \otimes (0.0349, 0.0396, 0.0449) = (0.1335, 0.1698, 0.2173)$$

In the second step, the degree of possibility of the fuzzy values can be estimated as follows:

Table 4: The degree of possibility of the fuzzy values

V(S1≥S2)	0.9484	V(S3≥S4)	0.8134
V(S1≥S3)	1.0000	V(S3≥S5)	1.0000
V(S1≥S4)	0.9564	V(S4≥S1)	1.0000
V(S1≥S5)	1.0000	V(S4≥S2)	0.9912
V(S2≥S1)	1.0000	V(S4≥S3)	1.0000
V(S2≥S3)	1.0000	V(S4≥S5)	1.0000
V(S2≥S4)	1.0000	V(S5≥S1)	0.5935
V(S2≥S5)	1.0000	V(S5≥S2)	0.5347
V(S3≥S1)	0.8610	V(S5≥S4)	0.7321
V(S3≥S2)	0.8078	V(S5≥S4)	0.5353

Source: The authors' calculation

In the third step, the weight vectors of the criteria are computed including:

$$d'(S_1) = V[(S_1 \geq S_2)\ and\ (S_1 \geq S_3)\ and (S_1 \geq S_4)\ and (S_1 \geq S_5)] = min(0.9484, 1.0000, 0.9564, 1.0000) = 0.9484$$
$$d'(S_2) = V[(S_2 \geq S_1)\ and\ (S_2 \geq S_3)\ and (S_2 \geq S_4)\ and (S_2 \geq S_5)] = min(1.0000, 1.0000, 1.0000, 1.0000) = 1.0000$$
$$d'(S_3) = V[(S_3 \geq S_1)\ and\ (S_3 \geq S_2)\ and (S_3 \geq S_4)\ and (S_3 \geq S_5)] = min(0.8610, 0.8078, 0.8134, 1.0000) = 0.8078$$
$$d'(S_4) = V[(S_4 \geq S_1)\ and\ (S_4 \geq S_2)\ and (S_4 \geq S_3)\ and (S_4 \geq S_5)] = min(1.0000, 0.9912, 1.0000, 1.0000) = 0.9912$$
$$d'(S_5) = V[(S_5 \geq S_1)\ and\ (S_5 \geq S_2)\ and (S_5 \geq S_3)\ and (S_5 \geq S_4)] = min(0.5935, 0.5347, 0.7321, 0.5353) = 0.5347$$
$$W' = (0.9484, \quad 1.0000, 0.8078, 0.9912, 0.5347)^T$$

In the fourth step, the normalized weight vectors are as follows:

$$\mathrm{W} = (0.2215, \ 0.2335, 0.1886, 0.2315, 0.1249)^T$$

- **With respect to the Fuzzy Row Sum Method which is Fuzzy Extent Analysis (FEA) with the centroid defuzzification method proposed by Ahmed and Kilic (2015)**

The first step is calculating the fuzzy synthetic extent value which is similar to Chang's method.

In the second step, despite estimating the degree of possibility of fuzzy values, the center of area is applied to calculate the fuzzy weights and normalize them. This step is performed as follows:

$$W' = \left(\frac{0.1605+0.2087+0.2689}{3}, \frac{0.1662+0.2142+0.2744}{3}, \frac{0.1511+0.1940+0.2511}{3}, \frac{0.1671+0.2133+0.2729}{3}, \frac{0.1335+0.1698+0.2173}{3}\right)^T$$
$$W' = (0.2127, 0.2183, 0.1987, 0.2178, 0.1735)^T$$

The normalized weight vectors are:

$$\mathrm{W} = (0.2083, 0.2138, 0.1946, 0.2133, 0.1700)^T$$

The weight values of sub-criteria are estimated similarly and are portrayed in Tables 3, 4, 5, 6, 7, 8.

Table 5: Fuzzy pairwise comparison matrice for the Accessibility sub-criteria

	AC1	AC2	AC3	AC4	AC5
AC1	**(1.0000,1.0000,1.0000)**	(0.7800, 0.9061, 1.0657)	(0.7348, 0.7759, 0.8280)	(0.5865, 0.6421, 0.7111)	(0.6856, 0.7396, 0.8091)
AC2	(0.9383, 1.1037, 1.2821)	**(1.0000,1.0000,1.0000)**	(0.7277, 0.8279, 0.9511)	(0.6609, 0.7784, 0.9367)	(0.5429, 0.6090, 0.6894)
AC3	(1.2078, 1.2889, 1.3610)	(1.0514, 1.2079, 1.3741)	**(1.0000,1.0000,1.0000)**	(0.7306, 0.8397, 0.9772)	(0.8589, 0.9190, 0.9905)
AC4	(1.4062, 1.5573, 1.7051)	(1.0676, 1.2847, 1.5131)	(1.0234, 1.1909, 1.3687)	**(1.0000,1.0000,1.0000)**	(1.0096, 1.0823, 1.1532)
AC5	(1.2360, 1.3520, 1.4587)	(1.4504, 1.6420, 1.8418)	(1.0096, 1.0881, 1.1643)	(0.8671, 0.9240, 0.9905)	**(1.0000,1.0000,1.0000)**
GCI = 0.0018 < 0.3700 → Consistency					

Source: The authors' calculation

Table 6: Fuzzy pairwise comparison matrice for the Environment sub-criteria

	EN1	EN2	EN3	EN4
EN1	**(1.0000,1.0000,1.0000)**	(0.7405, 0.8905, 1.0802)	(0.7800, 0.8492, 0.9367)	(0.5888, 0.6892, 0.8169)
EN2	(0.9257, 1.1229, 1.3503)	**(1.0000,1.0000,1.0000)**	(0.7277, 0.8539, 1.0000)	(0.6922, 0.8139, 0.9640)
EN3	(1.0676, 1.1776, 1.2821)	(1.0000, 1.1711, 1.3741)	**(1.0000,1.0000,1.0000)**	(0.8169, 0.9084, 1.0136)
EN4	(1.2242, 1.4511, 1.6984)	(1.0373, 1.2287, 1.4448)	(0.9866, 1.1008, 1.2242)	**(1.0000,1.0000,1.0000)**
GCI=0.0005 < 0.3563 → Consistency				

Source: The authors' calculation

Table 7: Fuzzy pairwise comparison matrice for the Efficiency sub-criteria

	EF1	EF2	EF3	EF4
EF1	**(1.0000,1.0000,1.0000)**	(0.8637, 1.0942, 1.3451)	(0.6118, 0.6661, 0.7249)	(0.3854, 0.4645, 0.5832)
EF2	(0.7435, 0.9139, 1.1578)	**(1.0000,1.0000,1.0000)**	(0.5786, 0.7149, 0.8909)	(0.4285, 0.5110, 0.6250)
EF3	(1.3795, 1.5013, 1.6345)	(1.1225, 1.3989, 1.7283)	**(1.0000,1.0000,1.0000)**	(0.6988, 0.8327, 0.9961)
EF4	(1.7147, 2.1527, 2.5946)	(1.5999, 1.9569, 2.3338)	(1.0039, 1.2009, 1.4310)	**(1.0000,1.0000,1.0000)**
GCI=0.0018 < 0.3563 → Consistency				

Source: The authors' calculation

Table 8: Fuzzy pairwise comparison matrice for the Travel cost sub-criteria

	TC1	TC2	TC3
TC1	**(1.0000,1.0000,1.0000)**	(1.0000,1.0000,1.0000)	(1.0000,1.0000,1.0000)
TC2	(1.0000,1.0000,1.0000)	**(1.0000,1.0000,1.0000)**	(1.0000,1.0000,1.0000)
TC3	(1.0000,1.0000,1.0000)	(1.0000,1.0000,1.0000)	(1.0000,1.0000,1.0000)
GCI= 0.0000 < 0.3147 → Consistency			

Source: The authors' calculation

Table 9: Fuzzy pairwise comparison matrice for the Safety - Security sub-criteria

	SS1	SS2	SS3
SS1	**(1.0000,1.0000,1.0000)**	(1.0000,1.0000,1.0000)	(0.9420, 0.9478, 0.9548)
SS2	(1.0000,1.0000,1.0000)	**(1.0000,1.0000,1.0000)**	(0.9420, 0.9478, 0.9548)
SS3	(1.0473, 1.0551, 1.0615)	(1.0473, 1.0551, 1.0615)	(1.0000,1.0000,1.0000)
GCI= 0.0000 < 0.3147 → Consistency			

Source: The authors' calculation

Table 10: The computed weight values on the basis of three methods

Criteria/Sub-criteria	Buckley (1986)		Chang (1990)		Ahmed & Kilic (2015)	
	Weight	Normalized Weight/ Local Weight	Weight	Normalized Weight/ Local weight	Weight	Normalized Weight/ Local Weight
EN	0.2126	0.2083	0.9484	0.2215	0.2127	0.2083
AC	0.2180	0.2135	1.0000	0.2335	0.2183	0.2138
EF	0.1988	0.1947	0.8078	0.1886	0.1987	0.1946
TC	0.2178	0.2133	0.9912	0.2315	0.2178	0.2133
SS	0.1737	0.1702	0.5347	0.1249	0.1735	0.1700
EN1	0.2148	0.2115	0.2600	0.1043	0.2149	0.2115
EN2	0.2375	0.2338	0.5052	0.2026	0.2376	0.2338
EN3	0.2658	0.2616	0.7288	0.2922	0.2652	0.2610
EN4	0.2978	0.2931	1.0000	0.4010	0.2985	0.2938
AC1	0.1604	0.1588	0.0000	0.0000	0.1598	0.1581
AC2	0.1696	0.1679	0.1166	0.0440	0.1704	0.1686
AC3	0.2067	0.2046	0.5817	0.2198	0.2060	0.2038
AC4	0.2404	0.2379	1.0000	0.3778	0.2396	0.2371
AC5	0.2332	0.2308	0.9487	0.3584	0.2348	0.2324
EF1	0.1875	0.1829	0.0000	0.0000	0.1898	0.1849
EF2	0.1886	0.1840	0.0000	0.0000	0.1868	0.1820
EF3	0.2818	0.2750	0.4950	0.3311	0.2785	0.2713
EF4	0.3671	0.3581	1.0000	0.6689	0.3714	0.3618
TC1	0.3333	0.3333	0.3333	0.3333	0.3333	0.3333
TC2	0.3333	0.3333	0.3333	0.3333	0.3333	0.3333
TC3	0.3333	0.3333	0.3333	0.3333	0.3333	0.3333
SS1	0.3152	0.3151	0.0000	0.0000	0.3274	0.3274
SS2	0.3152	0.3151	0.0000	0.0000	0.3274	0.3274
SS3	0.3697	0.3697	1.0000	1.0000	0.3453	0.3453

Source: The authors' calculation

4.2. Discussion

Table 11: Rankings of criteria and sub-criteria on the basis of three methods

				Buckley's method (1986)				Chang's method (1990)				Ahmed&Killic's method (2015)			
Main criteria	Local weight	Rank	Sub-criteria	Local weight	Rank	Global weight	Rank	Local weight	Rank	Global weight	Rank	Local weight	Rank	Global weight	Rank
EN	Buckley (0.2083) Chang	3	EN1	0.2115	4	0.0440	14	0.1043	4	0.0231	13	0.2115	4	0.0440	14
			EN2	0.2338	3	0.0487	13	0.2026	3	0.0449	12	0.2338	3	0.0487	13

				Buckley's method (1986)				Chang's method (1990)				Ahmed&Killic's method (2015)			
Main criteria	Local weight	Rank	Sub-criteria	Local weight	Rank	Global weight	Rank	Local weight	Rank	Global weight	Rank	Local weight	Rank	Global weight	Rank
	(0.2215) Ahmed&Killic (0.2083)		EN3	0.2616	2	0.0545	7	0.2922	2	0.0647	9	0.2610	2	0.0544	9
			EN4	0.2931	1	0.0610	6	0.4010	1	0.0888	3	0.2938	1	0.0612	5
			EN2	0.2338	3	0.0487	13	0.2026	3	0.0449	12	0.2338	3	0.0487	13
AC	Buckley (0.2135) Chang (0.2335) Ahmed&Killic (0.2138)	1	AC1	0.1588	5	0.0339	19	0.0000	5	0.0000	15	0.1581	5	0.0338	19
			AC2	0.1679	4	0.0358	16	0.0440	4	0.0103	14	0.1686	4	0.0360	16
			AC3	0.2046	3	0.0437	15	0.2198	3	0.0513	11	0.2038	3	0.0436	15
			AC4	0.2379	1	0.0508	11	0.3778	1	0.0882	4	0.2371	1	0.0507	11
			AC5	0.2308	2	0.0493	12	0.3584	2	0.0837	5	0.2324	2	0.0497	12
EF	Buckley (0.1947) Chang (0.1886) Ahmed&Killic (0.1946)	4	EF1	0.1829	4	0.0356	18	0.0000	3	0.0000	15	0.1849	3	0.0360	17
			EF2	0.1840	3	0.0358	17	0.0000	3	0.0000	15	0.1820	4	0.0354	18
			EF3	0.2750	2	0.0535	10	0.3311	2	0.0625	10	0.2713	2	0.0528	10
			EF4	0.3581	1	0.0697	4	0.6689	1	0.1262	1	0.3618	1	0.0704	4
TC	Buckley (0.2133) Chang (0.2315) Ahmed&Killic (0.2133)	2	TC1	0.3333	1	0.0711	1	0.3333	1	0.0772	6	0.3333	1	0.0711	1
			TC2	0.3333	1	0.0711	1	0.3333	1	0.0772	6	0.3333	1	0.0711	1
			TC3	0.3333	1	0.0711	1	0.3333	1	0.0772	6	0.3333	1	0.0711	1
SS	Buckley (0.1702) Chang (0.1249) Ahmed&Killic (0.1700)	5	SS1	0.3151	2	0.0536	8	0.0000	2	0.0000	15	0.3274	2	0.0556	7
			SS2	0.3151	2	0.0536	8	0.0000	2	0.0000	15	0.3274	2	0.0556	7
			SS3	0.3697	1	0.0629	5	1.0000	1	0.1249	2	0.3453	1	0.0587	6

Source: Author's calculation

The results calculated by Buckley, Chang, Ahmed, and Killic's methods show identical tendencies relating to the roles of criteria and sub-criteria in each group in evaluating the regional road network. AC is believed as the most important indicator to evaluate the road network performance with the weights at 0.2135, 0.2335, and 0.2138 for each approach. In this group, AC4 has the greatest weight accepted by three methods with the results at 0.2379, 0.3778, and 0.2371. Moreover, TC occupies the second rank in all criteria. TC1, TC2, and TC3 indicate similar results, showing the same influence on the regional logistics. In EF criteria which importance accounts for the fourth ranking, EF4 with weight values of 0.3581, 0.6689, and 0.3618 is claimed as the priority. This is appropriate since combining different types of vehicles increases route planning flexibility or even minimizes the costs. Lastly, the factor that is believed as the lowest priority in regional logistics performance is SS since it depends mainly on the driver's care. SS3 is considered the most significant in the group since it directly affects driver's safety and mitigates the number of accidents. The results are detailed in **Table 11**.

In particular, EN also plays a pivotal role in road network performance, especially EN4 – light pollution (accounting for 0.2931, 0.4010, and 0.2938 in three methods). In the Mekong Delta, the majority of good deliveries are scheduled at night, which makes it difficult for drivers to see. Thus, more infrastructural research relating to light pollution should be boosted. Cutting back on the use of fossil fuels (EN3) is the next important element in this group, which was also highlighted in the study about OECD countries conducted by C.-N. Wang et al. (2022).

Nevertheless, there have been significantly different findings of the global rank resulting with three specific methods because each technique employs different computation strategies. Buckley's method is based on the geometric mean method which is the most basic and simple one. To increase the accuracy, Chang's approach consists of two steps including computing the value of fuzzy synthetic extent with respect to the i^{th} object and calculating the degree of possibility for a convex fuzzy number to be higher than a k convex fuzzy number. However, because of the null value when estimating the degree of possibility, the weight also leads to the zero value (Lima-Junior & Carpinetti, 2020; Kınay & Tezel, 2021). Thus, Ahmed's method improves Chang's method by applying the first step of Chang's method and combining it with centroid defuzzification to calculate the priority weights. Consequently, the computation weights for each factor differ in each approach although local weights indicate a similar feature. In this study, despite the considerable differences compared to Chang's method, the top fourth highest sub-criteria in Buckley and Ahmed & Killic's methods are identical. According to Lima-Junior & Carpinetti (2020), the approach developed by Ahmed & Killic is considered to be optimal in the Fuzzy AHP method.

5. Conclusion

In general, this study is conducted to evaluate the sustainable logistics performance of the road network from Ho Chi Minh City to provinces in the Mekong Delta Region. The fuzzy AHP Approach was applied to analyze the role of 5 criteria which were divided into 19 sub-criteria. Moreover, in the step of calculating the priority weight, three approaches developed by Buckley (1985), Chang (1996), and Ahmed & Killic (2015) were scrutinized and compared.

On the basis of the three approaches, there are some equivalent results as well as differences. Generally, accessibility is believed to be the predominant criterion in evaluating the logistics performance of roads connecting provinces in the Mekong Delta Region. Meanwhile, environment-related criteria which play a pivotal role in developing sustainability are achieved at the third position. This is appropriate in the context of balancing between the economy and environmental protection of developing countries like Vietnam. Furthermore, light pollution reduction, port accessibility, servicing different transportation modes, minimizing any travel costs, and ensuring road signal systems are the most crucial standards in each group of criteria, which should be concentrated in the future. However, the global rankings between the three mentioned methods are significantly different because of their pros and cons. Generally, Ahmed & Killic's approaches are encouraged to apply.

Thus, there are some managerial implications that policymakers and enterprises can do to improve the road systems in the Mekong Delta Region. Firstly, accessibility and intermodality are encouraged in futuristic infrastructure schemes, especially the connectivity to commercial ports. Mekong Delta is well-known for its various river structures, thereby being an ideal condition to foster the network between road and marine transport. Moreover, increasing surveillance systems with cameras or smart devices is crucial. These innovations can ensure safety-security and measure and control the level of pollution on streets and highways. Finally, the regional electronic toll collection system which can minimize congestion, time, and operating costs should be unified. In fact, this system has been conducted in Vietnam since the beginning of 2022, but has not enacted in all provinces.

In spite of the above-mentioned advantages, there are some limitations of this study which are inspirations for research in the future. First of all, the following papers can expand the scope of evaluation to the road network in other regions in Vietnam or even the whole country to clarify the infrastructure potentials of these places. Moreover, the study for logistics performance can be conducted beyond the mentioned criteria or sub-criteria to explore the multidimensionality of road transport performance. The longitudinal studies can also gain insights into other modes of transport such as railways, airways, or marine systems which are potential transport infrastructures to develop the economy. Last but not least, other MCDM methods are also encouraged to boost the scientific value of this research tendency.

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