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Sustainable river-sea freight transport in major logistic gateways: a socio-economic and environmental performance evaluation of the United Kingdom's and Continental Europe's inland waterway transport

Sustainable River-Sea Freight Transport in Major Logistic Gateways: A Socio-Economic and Environmental Performance Evaluation of the United Kingdom's and Continental Europe's Inland Waterway Transport

Abstract

Purpose: The increasing complexity of supply chains and the corresponding demand for efficiency and reliability highlight the urgent need for enhanced performance and measurement standards. The drive for improved competitiveness is a central theme across all sectors, driving the demand for superior performance and high-quality services. Research on performance factors in the domain of inland waterway transport (IWT) is limited, and the existing studies lack the incorporation of practical methods that could effectively enhance the reliability of performance management results. Thus, this study aims to identify and analyse factors influencing performance perception in IWT and establish a benchmarking methodology for assessing UK IWT performance and four other European market leaders.

Design/methodology/approach: The paper uses the fuzzy-analytical hierarchy process (FAHP) and the technique for order preference by similarity to the ideal solution (TOPSIS) based methodology to support the IWT benchmarking process which is divided into three stages. First, the study identifies performance factors through literature analysis, and then, validates them through a structured questionnaire survey, In the second stage, the critical success factors are prioritized using FAHP and expert judgments. Finally, the UK's IWT performance was benchmarked with four European market leaders using the TOPSIS method.

Findings: The study identified 48 performance factors in IWT supply chains, categorized into eight: mobility and reliability, efficiency, profitability, environmental impact, infrastructure condition, safety, security, economic development, innovative transport technology, and policy formulation. Mobility and infrastructure conditions were found to be the most significant.

Research limitations/implications: The present study will contribute by enhancing the overall understanding of performance management within IWT supply chains. The performance factors identified, along with the structural hierarchy taxonomic diagram will create a detailed performance database.

Originality/value: This study uses empirical data to identify performance determinants in intermodal IWT supply chains. It contributes to the theoretical framework surrounding the measurement and standards of IWT supply chain performance. The study also adopts the fuzzy AHP method to evaluate and prioritize these performance factors to inform relevant stakeholders and policymakers of the most significant performance factors. Furthermore, this study serves as a preliminary reference for future research.

Keywords: *Inland waterways transport, Performance evaluation, Empirical study, Fuzzy-AHP, TOPSIS, Sustainable transport, River-sea freight transport*

1. Introduction

Globalisation and commercialisation, as key drivers, have significantly expanded the logistics chain's development, complexity, and competitiveness (Pondsorin and Ovsiannikova, 2021; Tae-Woo et al., 2024). This growth has placed substantial demands on intermodal transport networks, necessitating constant and integrated transport planning to enhance system reliability and efficiency. In response to the escalating pressure from the globalised market flow, the freight transportation industry has witnessed significant growth in recent decades (Liachovičius et al., 2023; Tjandra et al., 2024). The increasing demand and competition in freight transport can be ascribed to multiple sources, including globalisation (Fruth and Teuteberg, 2017; Dobre et al., 2021; Aryanpur and Rogan, 2024), variation in customers' preferences (Bernardino, 2015; Greve and Hansen, 2024), rapid advancements in Information and Communication Technology (ICT) (Chatti, 2021) and resources constraints experienced by both commercial and public services providers (Micheal et al., 2022). Simultaneously, the growing recognition of the external impact of transport has necessitated a shift towards more sustainable transport modes (Barrow et al., 2022; Calderon-Rivera et al., 2024(a).

European transport policies aim to optimize multimodal logistic chains, shifting towards sustainable and energy-efficient transport modes like rail, IWT, and short-sea shipping (Russell et al., 2019). The goal is to shift 30% of EU road freight over 300 km to sustainable modes by 2030, with a forecasted increase to 50% in 2050 (European Commission, 2020; Calderon-Rivera et al., 2024(b). Waterways for freight transportation have increased due to their role in Western European seaports and their integration into modern logistics chains, forcing the IWT industry to adapt and reinvent operations (Kotowska et al., 2018(a); Ken and Szostak, 2022; Pratas et al., 2023).

Nevertheless, statistics reveal that there has been a noticeable trend of stagnation in the transportation of goods over inland waterways throughout Europe in recent years (European Court of Auditors, 2015; Némethy et al., 2022). There is a prevailing preference for road transportation in the UK and the European freight transportation industry (Tardivo et al., 2022; Nkesah et al., 2023). The road remains the dominant mode of freight transportation, with rail and IWT having a smaller market share due to their inability to meet customer demands (Bernacki and Christian, 2024). High service quality leads to customer satisfaction and loyalty (Davis and Mentzer, 2006; Baki et al., 2009; Arabelen and Kaya, 2019). As supply chains expand, managing complex networks increases the risks of disruptions and inefficiencies (Gurzawska, 2019). To improve performance and competitive advantage, IWT transport modes must enhance services' quality, reliability, planning capabilities, operational traceability, and flexibility. The laborious aspect of IWT's substandard service quality limits their significance in the modal split. With small market shares and little competition, they face a vicious cycle of interdependence. According to Golner and Beškovnik (2021), a vicious cycle arises from this dynamic interdependence. Hence, it is necessary to explore new ground to deviate from routines while selecting a mode of transportation. Therefore, it is essential to create performance indicators that accurately capture the IWT's overall performance.

There are many taxonomies in practice because performance indicators are often established at individual or group levels for quality improvement and benchmarking. The goal is to establish a shared comprehension of definitions and measurement criteria to promote the widespread acceptance of standardised performance indicators across the sector. The inland waterway freight transport industry has been negatively impacted by these diverse nomenclatures, which makes comparisons nearly impossible. This phenomenon becomes particularly evident when managers are inclined to address their supply chain issues by implementing myopic solutions. Lowering uncertainty and improving distribution channel controls requires extensive ties and collaboration between businesses and their upstream and downstream suppliers and customers. Bozuwa et al. (2012) proposed specific applications of benchmarking methodologies that fail to capture certain critical IWT features. According to Kozerska (2016), performance measurement and process redesign are the primary methods for enhancing operational performance in the inland waterway sector. The concept of performance measurement is not novel. Firms and government agencies are compelled to enhance the transparency of their performance. Performance measurement is crucial for transparency in the transportation industry, especially in the IWT sector. However, inadequate performance indicators often lead to failures in innovative transport solutions, undermining the significance of IWT in multimodal supply chains

(Posset et al., 2009; Borca et al., 2023). Stakeholders must understand the underlying process and interconnected problems in freight transportation services delivery and supply chains. This is because factors such as reliability, planning, flexibility, quality, quantity, cost and traceability of operations are almost interconnected (Huang et al., 2019). The inland waterway freight transportation industry is experiencing rapid transformations, necessitating solutions to optimize logistic chain performance while maintaining reliability and flexibility (Paulauskas et al., 2022).

There has yet to be a comprehensive empirical study that examines all significant elements impacting performance in the IWT field in a single study. Such research would aim to evaluate and prioritise these performance factors to ascertain which are the most influential. The primary objective of this study is to develop a comprehensive system model that can identify and model all the key aspects and factors influencing performance perception in the domain of IWT. By doing so, we aim to bridge the gap in the existing literature and provide valuable tools for policymakers and stakeholders in the IWT sector. In order to achieve the objective of this research, this study will address three research questions.

RQ1. What are the main relevant factors determining the perception of performance in the IWT industry, and how can those influencing factors be addressed?

RQ2. What are the primary sources of performance factors impacting the efficiency and competitiveness of the IWT system, and how can these factors be identified and categorised?

RQ3. Which influencing factors are relatively more significant in improving the performance of the IWT network?

Thus, the study aimed to identify factors influencing performance perception in IWT, categorize and prioritize common factors using the fuzzy-analytical hierarchy process (FAHP), and evaluate and rank these factors by analysing their components. It benchmarked the UK's performance among four European IWT leaders using the technique for order preference by similarity to the ideal solution (TOPSIS) technique. The proposed methodology utilises the AHP and its fuzzy extension, known as fuzzy AHP. This approach replaces Saaty's 1-9 scales with membership scales and assigns weights to them to make more certain judgements in situations with vagueness.

Several fuzzy AHP applications have been described in the literature. These applications offer systematic methods for selecting alternatives and justifying problems by combining hierarchical structure analysis and fuzzy set theory (Mohsen et al., 2014; Stofkova et al., 2022; Ma et al., 2022; Akbar et al., 2023; Zakeri et al., 2023). Decision-makers often prefer to communicate interval judgments rather than fixed value judgments since the combination process is inherently uncertain (Toth and Vacik, 2018). Therefore, the research was conducted to identify the pertinent aspects and factors that influence the perception of performance in the domain of IWT, benchmark the performance of the UK's IWT using the FAHP in relation to these factors, and then rank the present case country compared to the European competitor using the TOPSIS method.

The subsequent sections of this work are structured as follows. Section 2 introduces briefly and provides an overview of the inland waterway freight transportation systems. Section 3 briefly reviews the literature on inland waterway freight transportation in the intermodal supply chain and its associated performance factors. Section 4 overviews the fuzzy set theory, fuzzy AHP approach, and TOPSIS method. Section 5 describes the proposed framework. Section 6 provides an empirical case study demonstrating how the proposed methodology is applied in a case study context. Section 7 presents some of the research implications, and the final section of this study, section 8, provides a comprehensive overview of the conclusions reached and discusses the limitations and potential areas for future research.

2. Inland Waterway Freight Transportation System

The process of IWT serves as a means to connect the operating procedures of pre-waterway carriage transportation (pre-carriage) and post-waterway carriage transportation (post-carriage). The system limits are established at both the port of departure and destination, encompassing the intermodal transhipment facilities. These facilities serve as the access points to the IWT system. Therefore, the point of access to the IWT system is the system boundaries established at the ports of departure and destination, including intermodal transhipment facilities. Physical components can be classified into two groups based on whether they are located on the land or waterside. Figure 1 depicts an IWT system's typical operational mechanism and physical components. The review and analysis from these studies do not consider the performance values of pre-carriage and post-carriage transportation, as the system does not directly impact them under investigation.

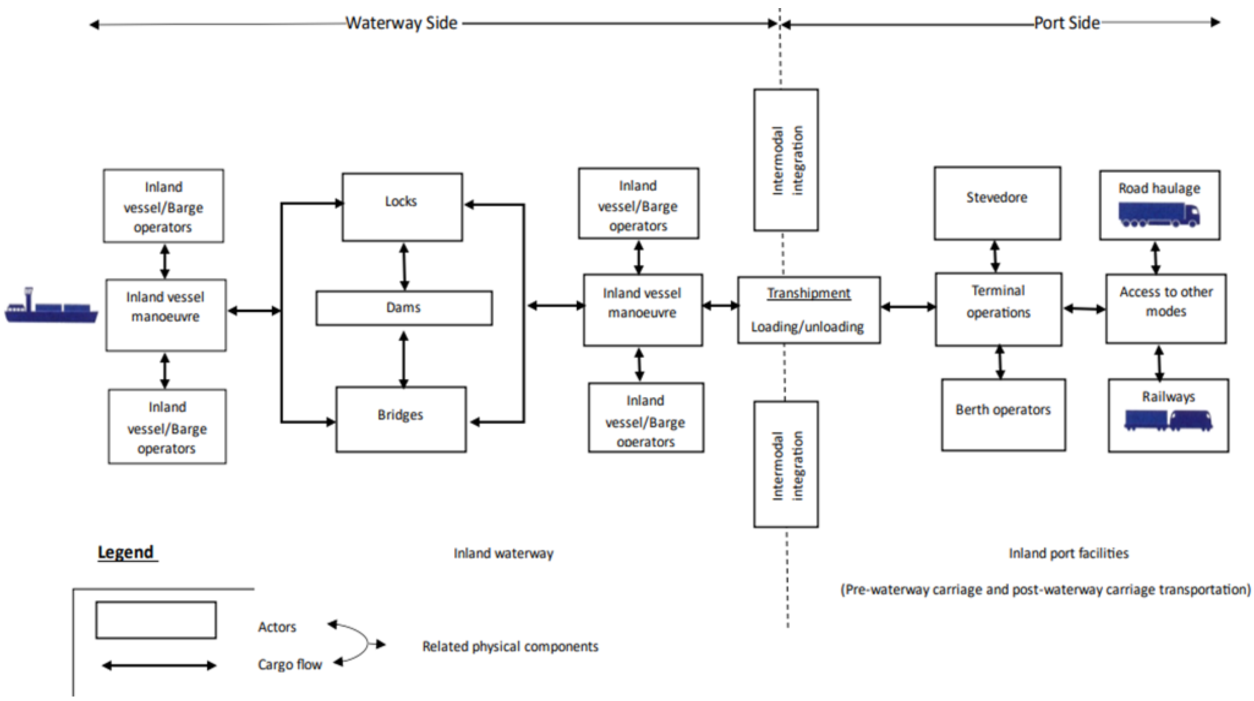

Figure 1: An IWT system's typical operational components and physical layout

Source: Authors' work

3. Literature Review

Performance measurement is crucial for controlling an organization's performance, enabling efficient management practices (Stuart, 1996; Dimitriou and Sartzetaki, 2022). Isoraite (2005) posits that performance measurement is an information system that enables management practices to operate efficiently. It combines quality, time flexibility, and cost measures, with standardized performance indicators. Most businesses use cost-focused approaches, identifying four major performance dimensions: cost, time, flexibility, and quality (De Toni and Tonchia, 2001). Research consistently highlights the importance of mobility and reliability as key metrics for freight transportation (Fossheim and Andersen, 2017; Ken and Szostak, 2022). Mobility is crucial for transport systems, enabling people, goods, and services to move between different socio-spatial environments. “Mobility” is related to the ability to move people and goods from one place to another, whilst “Reliability” relates to the degree of certainty and predictability of travel times (Borca et al., 2023). The capacity of vessel and waterway systems is essential for efficient freight movement. The emphasis on vessel and waterway system capacity underscores the reliability of these transit systems in facilitating efficient and dependable freight movement.

However, one of the significant challenges associated with IWT performance is scheduling problems at locks. Locks systems are crucial for IWT operations, enhancing connectivity, speed, safety, and reliability. Efficient locks are instrumental in minimizing delays and disruptions, whereas neglecting maintenance can lead to escalated costs (Wilson, 2006; Guan et al., 2021; Defryn et al., 2021; Hammedi et al., 2022). Passchyna et al. (2016) study proposes dynamic programming algorithms to enhance lockmaster's efficiency and vessel passage through inland waterways systems, considering factors like vessel attributes, environmental variables, and lock design. The research by Hekkenberg et al. (2017) focused on predictability and generalization and proposed performance indicators for managing dynamic fairway conditions, impacting speed, fuel consumption, sailing schedules, and transportation costs. Xing et al. (2013) highlight the importance of navigability in inland waterway system efficiency, impacting vessel velocity, capacity, reliability, and consistency of transportation services. Navigability is crucial for IWT systems, affecting efficiency, effectiveness, speed, safety, and costs. Durajczyk et al (2024) define the concept to encompass the ease with which vessels can traverse waterways, taking into account various elements such as depth, width, current barriers, and existing infrastructure.

Berthe et al. (2014), Jonkeren et al. (2014), and Christodoulou et al. (2020) study climate change's impact on inland vessels' navigability, carriage capability, and handling performance in EU freight hubs along the Rhine and Danube rivers. Schweighofer (2014), Vinke et al. (2022) and Dulder-Borca et al. (2023a) Dulder-Borca et al. (2023a) also summarise their work by implying that navigable waterways enable larger vessels and higher cargo movements, leading to economies of scale, improved transportation operations, and cost-effectiveness.

Global trade expansion and increased demand for transportation necessitate the establishment of reliable and well-maintained infrastructures to support these functions. Hossain et al. (2019) evaluated and emphasise the importance of infrastructure linking economic regions. The availability and quality of facilities like waterways, terminals, and railways directly influence the effectiveness and reliability of IWT (Farazi et al., 2021; Saeedi et al., 2022; Resetrepo-Arias et al., 2022; Dulder-Borca et al., 2023b; Schoeneich et al., 2023). Other researchers have highlighted that profitability and efficiency are vital components of evaluating the effectiveness of IWT networks (Golaka et al., 2022). The concept of profitability refers to the system's capability to generate income, a factor that is vital for the long-term sustainability of operations. Financial indicators, including return on investment and net profit margin, are utilized to measure this aspect (Gorcun et al., 2024). Conversely, efficiency pertains to the optimal use of resources such as fuel, labour, and time in the operational process. An efficient IWT system is characterized by its ability to minimize costs, curtail delays and boost throughput (Bazaluk et al., 2021; Barrow et al., 2022). Jonkeren et al. (2007) found that reduced water levels impact the Rhine IWT-market freight prices, while Karttunen et al. (2012) found that barge-based waterway transport offers a competitive advantage for Finnish forest chips.

The cost of IWT significantly impacts the competitiveness and efficiency of the sector (Kunroo and Alam, 2020). "Cost" refers to the financial resources needed for operation, maintenance, and investment in shipping and port infrastructure, including fuel, crew, and insurance expenditures. Similarly, Wiegmans and Konings' (2015) study reveals that roundtrips, drop-and-pick operations, and smaller containers improve intermodal IWT competitiveness, while high-cost terminal operations reduce it. Studies show IWTs are energy-efficient (Flodén et al., 2017; Santén et al., 2021), allowing cargo to travel longer and offering competitive transport costs, making them attractive for firms reducing carbon emissions, considering transportation time, cost, and infrastructure. Time is crucial in IWT, affecting vessel speed, scheduling, and maintenance. Increased speed leads to shorter transit times and increased operational efficiency, especially for timely goods delivery. The speed of a vessel is affected by multiple factors, such as the size, design of the ship, prevailing weather conditions, and the efficiency of its propulsion mechanisms (Guan et al., 2021). Similarly, Hekkenberg et al. (2017) examined factors influencing sailing time and transport cost for IWT demonstrated in a Rhine-Danube corridors case study and found uncertainty due to waterway conditions, ship variety, fairway conditions, propulsion power, and captain's behaviour. Maritime transport significantly contributes to air pollution, particularly in coastal regions (Keuken et al., 2014; Sys et al., 2020; Zhang et al., 2024). IWT is less efficient in reducing other pollutants than transportation $CO2$ emissions, but its benefits outweigh road freight transport emissions per tonnes-km (Bouckaert (2016; Grosso, 2021). Rigo et al. (2007) developed an integrated assessment methodology for evaluating the performance of contemporary intermodal IWT chains. The methodology considered factors such as logistics, economics, and environmental impact revealing poor NOX and PM performance primarily due to lower ship emission standards. Energy efficiency in IWT involves judicious cargo movement, minimizing environmental impact and economic costs by considering fuel consumption, emissions, and vessel capacity (Fan et al., 2024). Xing et al. (2013) analysed the operational energy efficiency of inland ships and found that inland navigation conditions significantly impact energy usage, GHG emissions, and operational efficiency of inland ships, while Segui et al. (2016) proposed an environmental performance baseline for the European inland port sector. Similarly, Lier and Macharis (2014) introduced the life-cycle assessment (LCA) method to evaluate the environmental impact of IWT services, highlighting the need for sustainability criteria.

Despite its potential environmental benefits, the IWT sector faces challenges due to high costs and limited funding, hindering the establishment of new services, fleet upgrades, and maintenance of waterborne infrastructure (He et al., 2024). These challenges, as highlighted by Camarago-Diaz et al. (2022) and Némenthy et al. (2022), underscore the need for comprehensive strategies and support to ensure the sustainability and growth of the IWT sector. Kalajdzic et al. (2022) proposed carbonisation strategies for the IWT sector, focusing on emission reduction funding and decarbonisation initiatives. Their research highlights the potential of transitioning to low-carbon or zero-emission systems, adopting energy-efficient technologies, and optimising vessel performance to reduce local air pollution. Tzannatos et al. (2016) found IWT services competitive and energy-efficient, but land-based services have better air quality due to stricter emission standards. Studies show that inadequate enforcement of emissions standards, monitoring, and stakeholder collaboration in the IWT industry hinders emission reduction measures and transportation system performance (Xing et al., 2013; Keuuken et al., 2014; Wang et al., 2020; Zhang et al., 2023b; He et al., 2024). The IWT industry's expansion raises environmental concerns, particularly noise pollution (Gray et al., 2021). Brusselaers and Momens (2022) discuss the environmental impact of noise pollution in IWT performance operations, suggesting investments in technologies, ship design standards, quieter routes, and speed restrictions. The quality of infrastructure plays a crucial role in determining the choice of freight transportation mode (Roso et al., 2020; Wehrle et al., 2022). Baroud et al. (2014) and Hossen et al. (2019) emphasize the significance of infrastructure quality, capacity, and reliability in ensuring effective, reliable, and safe transportation operations in IWT operations.

The IWT sector is expanding geographically, utilizing natural spatial distribution to improve routing and efficiency, driven by increasing global trade demand for long-distance transport (Li et al., 2023). Konings (2003) and Totakura et al. (2022) emphasize the need for optimizing IWT systems due to limited geographical expansion, natural distribution, and waterways' directions, despite the cost of artificial canal construction. In their work, Totakura et al. (2022) highlighted the inefficiency of inland waterway networks due to lack of main cargo flows, resulting in cost issues for trans-loading and transferring. Alias et al. (2020) and Grzelakowski (2024) suggest that improved infrastructure quality in critical network sections can enhance IWT's efficiency and competitiveness, despite significant spare capacity. Capital investment in navigation channels, canals, locks, and technology is crucial for maintaining infrastructure, as without it, it can deteriorate, leading to financial and potential disruptions (Beyer, 2018; Wehrle et al., 2022; He et al., 2024).

Păcuraru et al. (2015) highlighted the importance of investing in maintenance for efficient, environmentally friendly propulsion systems for inland vessels, reducing costs and minimizing emergency repairs. Hassel and Rashed's (2020) study reveal that new low-power vessels with hybrid/diesel-electric configurations are reliable, effective, and environmentally friendly, complying with emissions regulations, offering increased transportation capacity, optimized routes, and reduced operational expenses (Łebkowski, 2018; Kalajdžić et al., 2023). Meerseman et al. (2020) highlighted the significance of automation and autonomous vessels in fleet modernisation, integrating renewable energy sources and big data for improved fleet management. Safety and security are crucial in the IWT sector, ensuring efficient and seamless operation of vessels and ports (Martin et al., 2004; Maras, 2008; Xu et al., 2023).

Wang et al. (2017) and Yu et al. (2020) study key performance indicators for monitoring safety in IWT, emphasizing proactive measures like regular vessel inspections and maintenance. Additionally, other researchers underscore the significance of advanced navigation technologies and safety guidelines for operational security (Dorsser et al., 2020; Restrepo-Arias et al., 2022). Wang et al. (2020) compared IWT traffic performance with road and railway traffic, highlighting differences in reliability due to navigable river, technical, and operational conditions. Nevertheless, IWT offers unique advantages (Defryna et al., 2021; Zentari et al., 2022; Vinke et al., 2022).

Restrepo-Arias et al. (2022) emphasize the significance of vessel identification metrics in improving planning, optimizing shipping routes, and enhancing communication between vessels and shore-based infrastructure, thereby ensuring safety in IWT operations. In their study, Durajczky and Piotr (2022) assess the timeliness, completeness, and quality of vessel identification data, highlighting its critical role in ensuring safety in IWT operations. Research indicates that IWT significantly impacts economic productivity by enabling businesses to expand, reduce shipping costs, and streamline supply chain operations, leading to increased trade activity and job creation (Konings, 2003; Fratila et al., 2021).

Posset et al. (2009) emphasise the importance of economic development indicators in evaluating the IWT domain, including GDP contribution, job creation, trade volume, and aggregate added value. Marketing plays a crucial role in the IWT industry, enhancing service quality, brand reputation, sustainability, and innovation, while innovative transport technologies improve safety, efficiency, and sustainability (Grzelakowski, 2019; Collings et al., 2021). In their study, Asborno et al. (2022) found that implementing RIS on European inland waterways has improved safety, efficiency, and eco-friendliness, promoting mode transfer and easier waterway utilisation. Specht et al. (2020) examined the European River Information Services (RIS) concept to identify digital information services needed for improved planning decisions and specific planning tasks during transport operations. The study further reveals that the RIS, smart fairway, and RIS corridor management concepts, along with their related infrastructure, have proven to enhance the efficiency of IWT. Durajczyk's (2020) study evaluated and highlighted the importance of interoperability in the IWT domain, underlining its role in providing vessels with reliable navigation, traffic management, and metrological conditions, enhancing planning and logistics. Rahayu et al. (2024) emphasize the importance of establishing policies for efficient IWT performance, stating that effective protocols regulate standards and facilitate the movement of goods over water.

Mihic et al. (2012) and Totakura et al. (2022) suggest policy frameworks for assessing intermodal supply chain performance in IWT, emphasizing infrastructure enhancement, efficiency optimization, sustainability promotion, safety, security, and international cooperation. Santen et al. (2021) highlight collaboration, stakeholder cooperation, and joint infrastructure investments for improved transport performance in the IWT sector, while Praveen and Jegan (2015) and Vidan et al. (2012) emphasize education and skill development.

3.1. Research Gaps

The continuous expansion of the supply chain, along with the growing demand for sustainability, efficiency and reliability, highlights the urgent need for enhanced performance and measurement standards. Therefore, the demand for new methodologies and assessment tools to evaluate the performance of IWT has become evident. Correspondently, Grosso et al. (2021) identified various ways research can enhance IWT supply chains, such as offering objective evidence, developing methodologies, and facilitating knowledge transfer from the business sector and similar domains. It can be concluded that the primary challenge lies in the development of performance metrics that are applicable on an international scale, which are essential for facilitating accurate decision-making and enhancing competitiveness. Thus, additional research is required to explore the relevant process, the stakeholders involved, the unique characteristics of its operational setting and the breadth of the underlying system. The assertion is bolstered by the notion that competitiveness serves as a crucial element linking various industries, driving performance improvements and the delivery of high-quality services. Key determinants, including the state of infrastructure, policy, safety and security and environmental considerations, play a significant role in shaping the effectiveness of IWT. A comprehensive understanding of the various factors that influence performance perception in the IWT domain is crucial in this context. Hossain et al. (2019) highlighted that the existing research on performance metrics in IWT is limited. Furthermore, there is a significant gap in the empirical establishment and testing of clear categories that define the various aspects influencing the perception of performance throughout the IWT supply chains (Kalajdzic et al., 2022). There has yet to be a comprehensive empirical study that examines all significant elements impacting performance in the IWT field in a single study.

The present research seeks to bridge these gaps by establishing a three-phase methodology designed to empirically identify and classify the relevant performance factors that may influence the perception of performance in the IWT domain along with their subsequent ranking against four other countries. Examine and prioritize these performance elements to focus on the most impactful.

4. Methodology

This section presents a thorough methodology for performance assessment in the IWT domain. The research had several key phases. A fuzzy AHP has been utilised to investigate all relevant aspects and factors that are most likely to determine performance in the field of IWT. The suggested methodology has three stages (Dimitrios and Sartzetaki, 2022). In order to have a comprehensive understanding of the subject and identify the performance factors that determine performance perception in the domain of IWT, thorough and rigorous literature research is first done. A pilot study employing a five-point Likert scale questionnaire is carried out in the second phase. Experts in IWT, intermodal transport and supply chain management were contacted and asked to confirm the factors discovered. Following the identification of the most likely performance variable related to IWT, a pairwise comparison questionnaire was designed and given to experts to prioritise the performance factors that were ultimately determined based on the pilot study's findings. The fuzzy AHP was utilised to determine the weights and priorities of every element.

4.1. Fuzzy set theory

The Analytic Hierarchy Process (AHP) solves complex decisions by determining the relative importance of a cluster of activities in a problem. It is a problem decomposition method that breaks down complex multi-criteria decision problems into sub-problems in a hierarchical structure. It uses experts' opinions to devise a priority scale, addressing shortcomings of traditional methods like unbalanced judgment scales and uncertainty. Researchers have integrated fuzzy theory with AHP to address these issues and manage ambiguities in MCDM problems due to personal judgments and uncertainty arising from imprecision or vagueness.

Fuzzy set theory, introduced by Zadeh in 1965 (Zadeh, 1965), addresses uncertainty in subjective human thought and judgement. It uses triangular and trapezoidal fuzzy numbers to capture experts' uncertain, imprecise judgments using mathematical operations and programming. The fuzzy methods use fuzzy numbers to express attribute importance, providing consistency in real-world decision-making. Figure 2 displays a triangular fuzzy number (TFN).

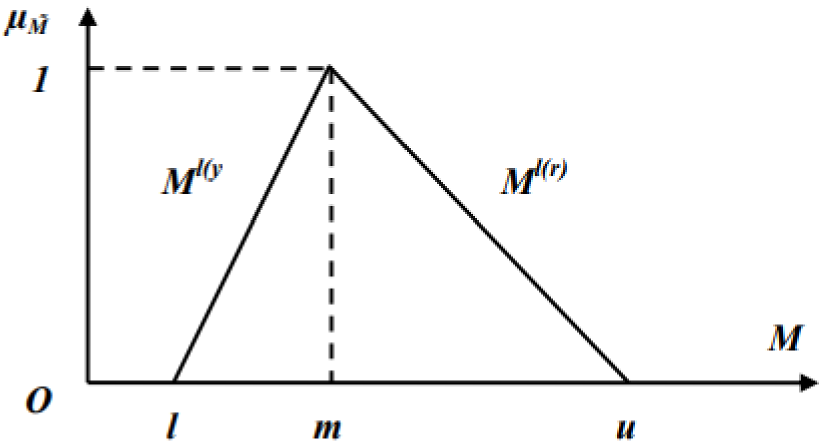

Figure 2. Triangular fuzzy number

Source: Khorasani et al. (2013)

Following the system described by Chang (1996), different elements have been considered to create a closed gap for an established fuzzy number.

This is represented as follows:

I) There exists $x0 \epsilon R$ such that $\mu M\ (x0) = 1$

II) for any $a\ \epsilon\ [0,1]$

$$Aa = [x, \mu A(x) \geq a]$$

The fuzzy number will be denoted simply by: $M \epsilon F(R)$

In this case, all fuzzy sets are defined by F(R), while the set of real numbers is denoted by R. A fuzzy number M on R will be a *TFN* if its membership function $\mu M\ (x): R\ \longrightarrow [0,1]$ is equivalent to the following Eq. (1):

$$u(x\backslash M) = \begin{cases} 0 & x < l \\ (x-l)/(m-l) & l \leq x \leq m \\ (u-x)/(u-m) & m \leq x\, u \\ 0 & x\ > u. \end{cases} \quad (1)$$

From Eq. (1) above, $l, m, u,$ define the smallest possible value, the most favourable value, and the most considered most possible, respectively. In this case, *u* and *l* represent the individual lower, and upper bounds of the fuzzy number M, and m refers to the modal value of M and $l \leq m \leq u$ (as shown in Eq. 1 above). Thus, TFN can be represented by $M = (l, m, u)$.

A non-fuzzy number is recognised by convention in cases where $l = m = u$.

A fuzzy number with its related representation (left and right) of each range of membership is as below:

$$M = (M^{l(y)}\ ,\ M^{l(r)})$$

$$= (l + (m-l)y, u + (m-u)y), y\ \epsilon\ [0,1] \quad (2)$$

In this case, the fuzzy number denotes the right-side representation $l(y)$ and $l(r)$denote the left side. Assume that $M_1$and M_2, $M_1 = (l_{1,}\ m_{1,}\ u_1)$ and $M_2 = (l_1\ m_2\ u_2)$ are to be two TFNs then the distance measurement of $d\ (M_1)$ is comparable to the Euclidean distance. The operational laws of the TFN $M_1 = (l_1\ m_1\ u_1)$ and $M_2 = (l_2\ m_2\ u_2)$ can be depicted as follows:

Addition of the fuzzy number $\oplus$

$M_1 \oplus M_2 = (l_1\ m_1\ u_1) \oplus (l_2\ m_2\ u_2)$

$$=\left(l_1 + l_{2,} + m_1 + m_2\ u_1 + u_2\right) \quad (3)$$

Multiplication of the fuzzy number $\otimes$

$M_1 \otimes M_2 = (l_1\ m_1\ u_1) \otimes (l_2\ m_2\ u_2)$

$$=(l_1 l_2 m_1 m_2\ u_1\ u_2) \quad (4)$$

Subtraction of the fuzzy number Θ

$M_1\ \Theta\ M_2 = (l_1\ m_1\ u_1)\ \Theta\ (l_2\ m_2\ u_2)$

$$=(l_1 -\ l_2,\ m_1 - m_2, u_1 - u_2) \quad (5)$$

Division of a fuzzy number Ø

M_1 Ø M_2 = $(l_{1,}\ m_{1,}\ u_1)$ Ø $(l_{2,}\ m_{2,}\ u_2)$

$M^{-1} = (l_{1,}m_{1,}\ u_1)^{-1} = (1/u_{1,}\ 1/m_{1,}\ 1/l_1)$ (6)

$\lambda \otimes M_1 = (\lambda l_{1,}\ \lambda m_{1,}\ \lambda u_1)$ Where $\lambda > 0$, $\lambda \in R$ (7)

Reciprocal of the fuzzy number

$M_1^{-1} = \frac{l}{l_1}, \frac{l}{m_1}, \frac{l}{u_1}$ (8)

4.2. Fuzzy analytic hierarchy process

The generally acknowledged fuzzy AHP method is presented by Chang (1992, 1996) as its extended analysis method uses the extended analysis technique for the synthetic extent values of pairwise comparisons. According to Chang's technique of extended analysis, an extended goal analysis is created for each object as extended goal analysis is created. The methodology proposed by Chang uses linguistic variables to describe the relative judgements given by experts. Suppose that $X = \{x1, x2, \ldots \ldots, xn\}$ be an object set and $U = \{u1, u2, \ldots \ldots um\}$ is the number of aims. An individual object xi, is assumed, and an extended analysis is achieved for each goal, g_i. Therefore "m" for an individual object can be represented as follows:

$$M_{gi,}^1\ M_{gi}^2 \ldots \ldots M_{gi,}^m \qquad i = 1,2, \ldots, n \qquad (9)$$

In the FTN whose parameters are depicted as follows:

$$M_{gi,}^j \quad (j = 1,2, \ldots, m)$$

The least, most and considered most possible values are represented as (l, m, u).

The method follows the steps described by Chang's expanded analysis (1996), which includes the following steps (Kahraman et al., 2003, 2004; Kabir et al., 2011; Sequeira et al., 2020):

(Step I). Compute the value of the fuzzy synthetic extent for the ith object with according to Eq. (3.10)

$$s_i = \sum_{j=1}^{m} M_{gi}^j \otimes \left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^j\right]^{-1} \qquad (10)$$

Where $\sum_{j=1}^{m} M_{gi}^j$ is obtained by performing the fuzzy addition operation of m extent analysis values for a particular matrix such that:

$$\sum_{j=1}^{m} M_{gi}^j = \left(\sum_{j=0}^{m} l_{gi}, \sum_{j=1}^{m} m_j, \sum_{j=1}^{m} u_j\right), \qquad (11)$$

and to obtain $[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{j}]^{-1}$ perform the fuzzy addition operation of M_{gi}^{j} $(j = 1, 2, \ldots m)$ values such that:

$$\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{j}\left(\sum_{i=1}^{n} l_i, \sum_{i=1}^{n} m_i, \sum_{i=1}^{n} c_i\right) \quad (12)$$

and then compute the inverse of vector the in Eq. (3.12) such that:

$$\left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{j}\right]^{-1} = \left(\frac{1}{\sum_{i=1}^{n} u_i}, \frac{1}{\sum_{i=1}^{n} m_i}, \frac{1}{\sum_{i=1}^{n} l_i}\right) \quad (13)$$

(Step II). In computing the degree of possibility, two fuzzy synthetic extents are considered for comparisons, which entails choosing the largest or smallest number's fuzzy value. The degree of possibility of M_2 $(l_2 m_2 u_2) \geq M_1 = (l_1 m_1 u_1)$ is defined as follows:

$$V\ (M_2 \geq M_1) = \text{sup}\ [\ \text{min}\ (\mu_{M1}\ (x)\ ,\ \mu_{M2}\ (x))\ ] \quad (14)$$

an equivalently defined as follows:

$$\text{V}\ (M_2 \geq M_1) = \begin{cases} 1 & \\ 0 & Otherwise \quad if\ m_2 \geq m_1 \\ \frac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)} & if\ l_1 \geq u_2 \end{cases} \quad (15)$$

Eq.12 shows where d is the ordinate of the highest intersection point D between μM_1 and μM_2 as illustrated in Figure 3.6 below. To compare M_1 and M_2, it requires both the values of $V(M_1 \geq M_2)$" and $V(M_2 \geq M_1)$.

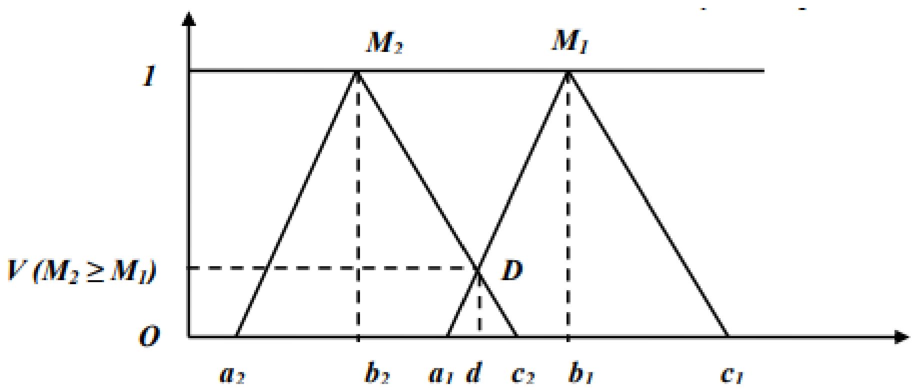

Figure 3: The intersection between $\boldsymbol{M_1}$ and $\boldsymbol{M_2}$

Source: Kahraman et al. (2003)

(Step III). To compute the degree of possibility for a convex fuzzy number to be greater than k we use convex fuzzy numbers M_i $(i = 1, 2, \ldots, k)$. These can be defined according to Eq. (16).

$$V\ (\text{M} \geq M_1, M_2 \ldots, M_k) = V\ [(\ M\ \geq\ M_1)\ \text{and}\ (M\ \geq\ \text{M})\ \text{and}\ \ldots\ (\ M\ \geq\ M_k)] = \text{min}\ V\ (\text{M} \geq\ M),\ (i = 1, 2, 3, \ldots k). \quad (16)$$

Assuming that

$d'(A_1)$ = min V $(S_i \geq S_k)$ (17)

for $k = 1, 2, 3, \ldots, n; k \neq i$. Then the weight vector is given by W' =($d'(A_1)$, $d'(A_2)$,…, $d'(A_n))^T$ (18)

Where Ai = $(i = 1, 2, 3, \ldots n)$ are n elements

(Step VI). By normalising, the normalised weight vectors are

W = $(d(A_1), d'(A_2) \ldots d'(A_n))^{\mathrm{T}}$ (19)

Where W does not represent a fuzzy number.

4.3. TOPSIS method

Hwang and Yoon (1981) developed TOPSIS as one of the classic MCDM methods widely used for ranking problems. These techniques are characterized by their simplicity and ease of implementation, appealing to users who prefer a more basic weighting approach. The TOPSIS method is established on a simple and intuitive concept that a chosen alternative should contain the shortest distance from the positive-ideal solution (PIS) and the farthest from the negative-ideal solution (NIS) (Wang and Lee, 2007; Lin et al., 2008; Zyoud et al., 2016; Chakraborty, 2022). In other words, the positive-ideal solution has the most benefits and lowest cost of all alternatives (achieving minimal gaps in each criterion). The negative-ideal solution has the lowest and highest costs (achieving the maximal levels in each criterion). The positive-ideal solution comprises all the best values attainable to the criteria, whereas the negative-ideal solution comprises all the worst values attainable to the criteria (Zulqarnain et al., 2020). Numerous research efforts have integrated Fuzzy AHP and TOPSIS into their methodologies. For instance, Mehdi et al. (2022) have proposed a fuzzy AHP-TOPSIS model for the evaluation of urban and public transportation systems. Khorasani et al. (2013) developed a fuzzy AHP-TOPSIS model for road safety performance evaluation in the freight transport industry. Ersoy (2021) developed a framework that integrated the fuzzy AHP-TOPSIS to assess the weight of each performance criterion and systematically rank the measures associated with implementing airports' performance. Kalem et al. (2024) presented a model based on a fuzzy AHP-TOPSIS to evaluate the performance of railway freight transport infrastructure. The TOPSIS method is computed in the following manner:

I). Construct normalised decision matrix.

Various attribute dimensions are transformed in this step into non-dimensional attributes, allowing comparisons over criteria. Normalise scores or data as follows:

r_{ij} = x_{ij} / ($\sum x^2$ for i = 1, …, m; $j = 1, \ldots, n$ (20)

(II). Construct the weighted normalised decision matrix.

Assuming that we have a set of weights for each criterion w_j for $j = 1, \dots, n$. Each column of the normalised decision matrix is multiplied by its associated weight. The new matrix element is:

$v_{ij} = w_j = r_{ij}$, for $i, \dots, m; j = 1, \dots, n$ (21)

(III). Determine the positive ideal and negative ideal solutions.

Where the positive ideal solution is:

$A' = \{v_1{}^*, \dots, v_n{}^*\}, where\ v_j{}^* = \{max(v_{ij})\ if\ j \in J\ ; min\ (v_{ij})\ if\ j \in J'\}$ (22)

And where negative ideal solution is:

$A' = \{v_1{}', \dots, v_n{}'\}, where\ v' = \{\min\ (v_{ij})\ if\ j \in J\ ; max\ (v_{ij})\ if\ j \in J'\}$ (23)

(IV). Calculate the separation measures for each alternative.

The separation from the ideal alternative is:

$D_i{}^* = [\ \sum(v_j{}^* - v_{ij})^2\ ]^{1/2} \qquad i = 1, \dots, m$ (24)

The separation from the negative ideal alternative is similar as:

$D' = [\ \sum(v_j{}' - v_{ij})^2\ ]^{1/2} \qquad i = 1, \dots, m$ (25)

(V). Calculate the relative closeness to the idea solution $\mathrm{CC_i} *$

$CCi^* = S'_i\ /\ (S_I * + S'_I), \qquad 0 < CCi * < 1$ (26)

(VI). By comparing $\boldsymbol{CCi}$ values, the ranking alternatives are determined.

5. Proposed Fuzzy-Analytical Hierarchy Process and TOPSIS Method Framework

A fuzzy-AHP and TOPSIS framework has divided the work into three distinct phases, as seen in Figure 4. The framework identifies and prioritises all relevant aspects and factors that determine the perception of performance in IWT.

5.1 Phase 1. Identification of performance factors in the domain of IWT.

The research will review existing literature to identify factors influencing performance perception in IWT supply chains. A performance taxonomic diagram will be developed, validated by experts, and evaluated to provide a suitable model for classifying performance in this context.

5.2 Phase 2. A fuzzy analytical hierarchy process is used to determine the weights and prioritise the performance factors in an intermodal supply chain.

This study uses fuzzy AHP to evaluate the performance variables of IWT in the UK and European settings, comparing individual variables pairwise. Experts provide subjective inputs using the scale shown in Table 1 and, fuzzy AHP is used to achieve definitive judgments by replaying Saaty's 1-9 scales with membership scales.

5.3 Phase 3 Ranking of the UK's IWT based on the critical success factors among four others European IWT using the technique for order preference by similarity to ideal solution (TOPSIS) method. The UK's IWT's performance levels are compared to four European market leaders using the TOPSIS approach, based on critical success factors analysed using fuzzy AHP. The benchmark also depicts their relative ranking.

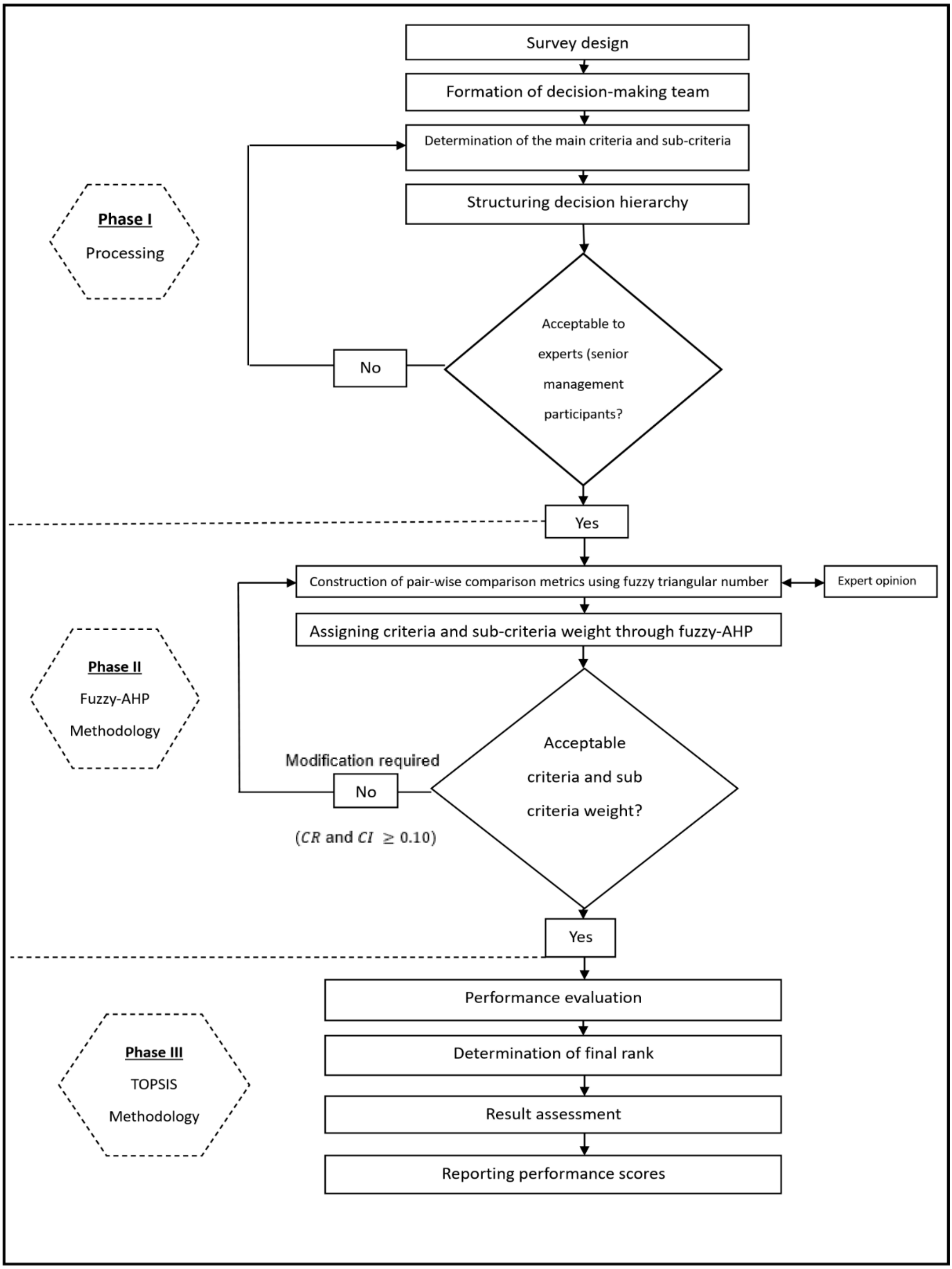

Figure 4: Schematic diagram of the proposed model for performance evaluation

Source: Authors' work

Table 1: Linguistic variable describing weights of the criteria and values of ratings

Linguistic scale for importance	Fuzzy numbers	Membership function	Domain	Triangular fuzzy scale $(\boldsymbol{l}, \boldsymbol{m}, \boldsymbol{u})$
Just equal	$\tilde{1}$			$(1, 1, 1)$
Equally important		$\mu_{\acute{M}}(x)$ = (3-x) / (3-1)	$1 \leq x \leq 3$	$(1, 1, 3)$
Weakly important	$\tilde{3}$	$\mu_{\acute{M}}(x)$ = (1-x) / (3-1)	$1 \leq x \leq 3$	$(1, 3, 5)$
		$\mu_{\acute{M}}(x)$ = (5-x) / (5-3)	$3 \leq x \leq 5$	
Essential or strongly	$\tilde{5}$	$\mu_{\acute{M}}(x)$ = (x-3) / (5-3)	$3 \leq x \leq 5$	
				$(3,5,7)$
Important		$\mu_{\acute{M}}(x)$ = (7-x) / (7-5)	$5 \leq x \leq 7$	
Very strongly	$\tilde{7}$	$\mu_{\acute{M}}(x)$ = (x-5) / (7-5)	$5 \leq x \leq 7$	
				$(5,7,9)$
Important		$\mu_{\acute{M}}(x)$ = (9-x) / (9-7)	$7 \leq x \leq 9$	
Extremely important	$\tilde{9}$	$\mu_{\acute{M}}(x)$ = (x-7) / (9-7)	$7 \leq x \leq 9$	$(7,9,9)$

Source: Kabir et al. (2011)

From Table 1 above, if factor i has one of the above numbers allocated to it corresponding to factor j, then j has the same value as i. Reciprocals of above M_1^{-1} = $({}^{1}/_{u_{1,}}\ {}^{1}/_{m_{1,}}\ {}^{1}/_{l_1})$. The Linguistic variables for the significance of each criterion's weight are illustrated in Figure 5 below.

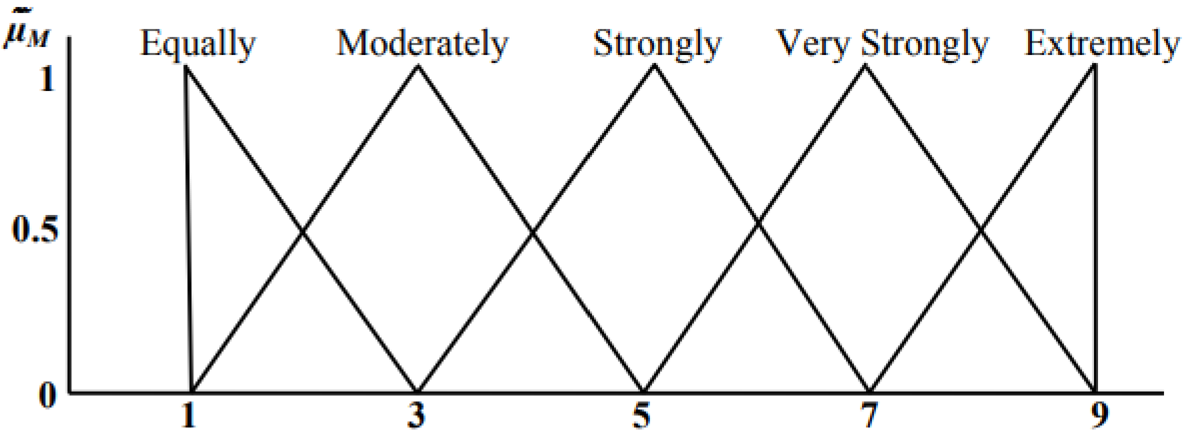

Figure 5: Linguistic variables for the importance weight of each criterion

Source: Sequeira et al. (2020)

6. An application of the proposed methodology in the IWT industry

6.1 Case description

The freight transport industry faces increasing pressure from globalized markets, with road transport absorbing most of the growth (Takman and Gonzale-Aregall, 2023). European experts predict a 40% growth by 2030 and 80% by 2050, necessitating measures to handle this growth (Tjandra et al., 2024).

In Western Europe, major seaports rely on IWT for efficient connectivity. A well-functioning supply chain is crucial for meeting customer demands, reducing costs, and gaining a competitive advantage (Némethy et al., 2022). Identifying and modelling factors influencing IWT performance is essential. The IWT industry is increasingly reliant on maritime access due to pressures caused by globalization. European seaports with inland waterway network connectivity form an interface, leading to increased waterborne transport in countries like the Netherlands, Belgium, Hamburg, and France (Gattuso et al., 2023). This integration has led to complex organizational structures that leverage cost, capacity, and regularity advantages, offering better adaptability and flexibility than the rail network. Meanwhile, the UK's dormant inland waterway infrastructure offers sustainable commercial benefits for freight transportation, contributing to sustainable transport development (Wiagmans, 2018). Despite its marginal role in the UK freight transportation system, the advantages of moving freight onto waterways align with government priorities and environmental policies, making waterways a viable option for freight transportation (Terziev et al., 2023).

6.2 Data Collection

The research involved three phases: identifying performance factors influencing perception in IWT, analysing field performance using fuzzy AHP, and benchmarking the UK's IWT against European market leaders using the TOPSIS approach. Experts were selected based on experience and medium-to-senior positions, and a structured questionnaire was developed for participant participation.

6.2.1 Step 1: Identification of an integrated set of indicators for assessing IWT performance

The research identified 48 performance factors, classified into eight primary and 48 subcategories, and created the first hierarchical performance taxonomy diagram. A structured questionnaire was developed to verify these factors and validate the taxonomy diagram. Expert panel participants were carefully selected for validation, ensuring fairness and reliability using a seven-point Likert scale. Table 2 contains comprehensive details and information provided by experts. After analysis, several performance factors were excluded, and the categorization was modified.

6.2.2 Step 2: Prioritisation of performance criteria and sub-criteria using fuzzy AHP

The study analysed performance categories, types, and elements, obtaining expert data through a pairwise comparison questionnaire. The expert's profile is presented in Table 2. It used the average value technique to compare linguistic variables' importance at different hierarchical levels. The subjective phrases were converted into triangular fuzzy numbers using linguistic scales.

Therefore, the fuzzy-AHP methodology is used to address ambiguity and lack of precision in subjective IWT benchmarking decisions. It allows experts to make flexible judgments, providing a more nuanced understanding of the complex decision-making process. A decision matrix 'D' in Table 4 consists of 8 x 8 elements and may be constructed to measure each critical success factor's relative degree of importance based on the proposed methodology.

Table 2: Respondent profiles (Fuzzy AHP pairwise comparison)

		No
Type of Operating Organisation?	Head of Project/Managing authority	8
	Academicians	2
	Projects officer/Project partners	5
	Monitoring coordinator	1
	Head of supply chain consulting firm/logistics/warehousing/consolidators	3
	Head of marketing/Corporate/Public affairs	5
	Others	3
Country(ies)	France	3
	The Netherlands	6
	Germany	5
	Belgium	4
	UK	9
Job tittle and position (Expertise)	Consultants working in the supply chain and IWT	7
	Professional in inland navigation/intermodal transportation projects	8
	Academicians from transport and logistics background	2
	Inland waterways technology companies	4
	Value-added services (VAS) professional (warehousing and consolidators)	2
	Legitimising agents	4
	Others	0
Inland waterways you are familiar or indirectly involved with?	Le-Hare-Seine-Paris corridor	4
	Rotterdam, Hamburg, and Antwerp coastal gateways	7
	Rhine-Main-Danube corridor	9
	Thames and the Liverpool/Manchester regional gateway	6
	Others	1
Years of professional working experience	1 – 5 Years	0
	6 – 10 Years	4
	11 -15 Years	10
	16 – 19 Years	5
	20 Years above	8

Source: Authors' work

6.2.3 Step 3: ranking of alternative using TOPSIS

The study used fuzzy AHP weight and TOPSIS method to rank alternatives, followed by an expert opinion survey to determine the selected alternative, the quality of the expert judgment is built based on their proficiency, capability, experience, and knowledge in the relevant area. Table 3 provides the expert's respondent profiles and Figure 6 depict the final hierarchical structure for the set of indicators for IWT performance.

Assessment

Table 3: Respondent profiles (TOPSIS)

No	Expertise	Position	Country of Operation
1	Inland waterway project delivery partner	Project Head	Antwerp, Hamburg, and UK
2	Consultants working in supply chain	Consultants	Europe and the UK
3	Marine experts (inland port official)	Port officer	Europe (Rhine and Danube)
4	Project officer/partner	Partner	UK and Hamburg
5	Inland waterway project delivery partner	Head of section	Seine region
6	Academician from transport and logistic background	Head of stimulator	The Netherlands
7	Legitimising agent	IWT agent	Netherlands
8	Inland waterway project delivery partner	Partner	Belgium and the UK
9	Inland waterway project delivery partner	Partner	Europe
10	Maritime transport experts	Marine of operations	Belgium and Antwerp
11	IWT Logistic service company	Consultant	Europe
12	Maritime transport experts	Consultant	Worldwide
13	Academician from transport and logistic background	Senior lecturer	Antwerp and Belgium
14	Waterway agency	Clearing and forwarding	Rhine port

Source: Authors' work

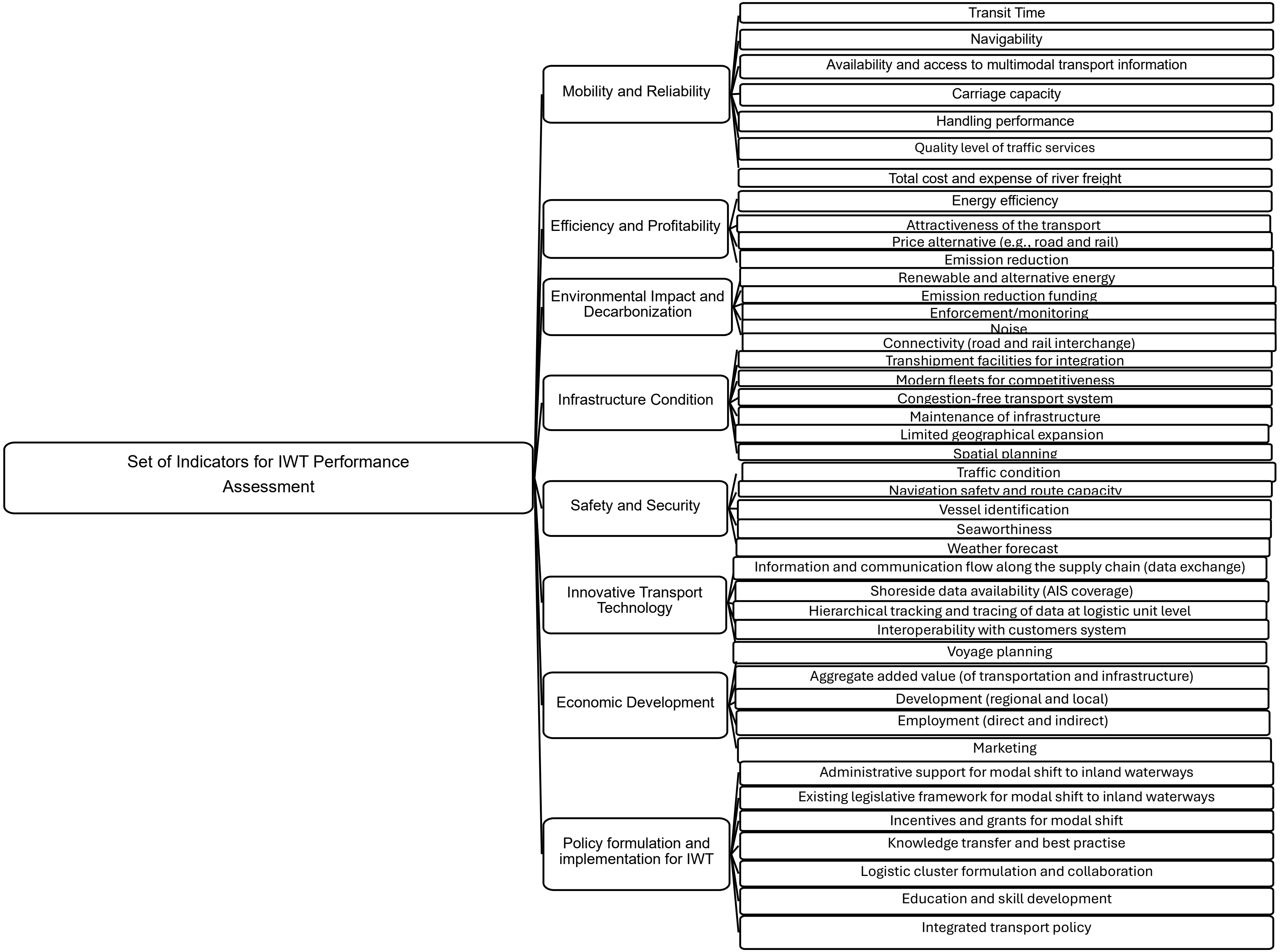
Set of Indicators for IWT Performance Assessment
Mobility and Reliability
Transit Time
Navigability
Availability and access to multimodal transport information
Carriage capacity
Handling performance
Quality level of traffic services
Total cost and expense of river freight
Efficiency and Profitability
Energy efficiency
Attractiveness of the transport
Price alternative (e.g., road and rail)
Environmental Impact and Decarbonization
Emission reduction
Renewable and alternative energy
Emission reduction funding
Enforcement/monitoring
Noise
Connectivity (road and rail interchange)
Infrastructure Condition
Transhipment facilities for integration
Modern fleets for competitiveness
Congestion-free transport system
Maintenance of infrastructure
Limited geographical expansion
Spatial planning
Safety and Security
Traffic condition
Navigation safety and route capacity
Vessel identification
Seaworthiness
Weather forecast
Innovative Transport Technology
Information and communication flow along the supply chain (data exchange)
Shoreside data availability (AIS coverage)
Hierarchical tracking and tracing of data at logistic unit level
Interoperability with customers system
Voyage planning
Economic Development
Aggregate added value (of transportation and infrastructure)
Development (regional and local)
Employment (direct and indirect)
Marketing
Policy formulation and implementation for IWT
Administrative support for modal shift to inland waterways
Existing legislative framework for modal shift to inland waterways
Incentives and grants for modal shift
Knowledge transfer and best practise
Logistic cluster formulation and collaboration
Education and skill development
Integrated transport policy

Figure 6: Final hierarchical structure

Sources: Authors' work

Table 4: The fuzzy pair-wise comparison matrix of eight criteria

	SC_1	SC_2	SC_3	SC_4	SC_5	SC_6	SC_7	SC_8
SC_1	(1.000,1.000,1.000)	(1.000,3.077,4.500)	(0.400,2.120,4.500)	(0.222,1.253,4.500)	(0.222,0.721,3.500)	(0.500,2.484,4.500)	(0.500,2.118,4.500)	(0.500,2.692,4.500)
SC_2	(0.222,0.325,1.000)	(1.000,1.000,1.000)	(0.222,0.465,2.000)	(0.222,0.694,2.500)	(0.667,1.000,2.000)	(0.400,0.990,3.500)	(0.286,0.759,2.500)	(0.286,0.855,3.500)
SC_3	(0.222,0.472,2.500)	(0.500,2.151,4.505)	(1.000,1.000,1.000)	(0.222,1.102,4.500)	(0.286,1.313,4.500)	(0.286,1.109,3.500)	(0.286,1.197,4.500)	(0.286,1.618,4.500)
SC_4	(0.222,0.798,4.505)	(0.400,1.441,4.505)	(0.222,0.907,4.505)	(1.000,1.000,1.000)	(0.286,1.338,4.500)	(0.400,1.113,4.500)	(0.286,1.355,4.500)	(0.400,2.265,4.500)
SC_5	(0.286,1.387,4.505)	(0.500,1.000,1.499)	(0.222,0.762,3.497)	(0.222,0.747,3.497)	(1.000,1.000,1.000)	(0.286,1.251,3.500)	(0.286,1.015,3.500)	(0.500,2.509,4.500)
SC_6	(0.222,0.403,2.000)	(0.286,1.010,2.500)	(0.286,0.902,3.497)	(0.222,0.898,2.500)	(0.286,0.799,3.497)	(1.000,1.000,1.000)	(0.222,0.997,4.500)	(0.400,2.294,4.500)
SC_7	(0.222,0.472,2.000)	(0.400,1.318,3.497)	(0.222,0.835,3.497)	(0.222,0.738,3.497)	(0.286,0.985,3.497)	(0.222,1.003,4.505)	(1.000,1.000,1.000)	(0.500,2.588,4.500)
SC_8	(0.222,0.371,2.000)	(0.286,1.170,3.497)	(0.222,0.618,3.497)	(0.222,0.442,2.500)	(0.222,0.399,2.000)	(0.222,0.436,2.500)	(0.222,0.386,2.000)	(1.000,1.000,1.000)

Source: Authors' work

SC_1 = (4.34, 15.46, 31.50) ⊗ (1/206, 1/73.46, 1/25.87) = (0.021, 0.211, 1.218)

SC_2 = (3.31, 6.09, 18.0) ⊗ (1/206, 1/73.46, 1/25.87) = (0.016, 0.083, 0.696)

SC_3 = (3.09, 9.96, 29.51) ⊗ (1/206, 1/73.46, 1/25.87) = (0.015, 0.136, 1.140)

SC_4 = (3.22, 10.22, 32.52) ⊗ (1/206, 1/73.46, 1/25.87) = (0.016, 0.139, 1.257)

SC_5 = (3.30, 9.67, 25.50) ⊗ (1/206, 1/73.46, 1/25.87) = (0.016, 0.132, 0.986)

SC_6 = (2.92, 8.30, 23.99) ⊗ (1/206, 1/73.46, 1/25.87) = (0.014, 0.113, 0.927)

SC_7 = (3.07, 8.94, 25.99) ⊗ (1/206, 1/73.46, 1/25.87) = (0.015, 0.122, 0.999)

SC_8 = (2.62, 4.82, 18.99) ⊗ (1/206, 1/73.46, 1/25.87) = (0.013, 0.066, 0.743)

Eqs.6.15 and 6.16, respectively, can then be used to calculate the degree of possibility of the superiority of 1 which is denoted by $V\ (SC_1 \geq SC_2)$. Therefore, the degree of possibility of the superiority for the requirement is calculated as

$V\ (SC_1 \geq SC_2) = 1$ $V\ (SC_1 \geq SC_3) = 1$ $V\ (SC_2 \geq SC_4) = 1$

$V\ (SC_1 \geq S_5) = 1$ $V\ (SC_1 \geq S_6) = 1$ $V\ (SC_1 \geq S_7) = 1$

$V\ (SC_1 \geq S_8) = 1$

The value for the second requirement is calculated as:

$$V\ (SC_2 \geq SC_1) = \frac{0.021-0.696}{(0.083-0.696)-(0.211-0.021)} = \frac{-0.675}{-0.803} = 0.841$$

$V\ (SC_2 \geq SC_3) = 0.927$ $V\ (SC_2 \geq S\ C_4) = 0.923$ $V\ (SC_2 \geq S\ C_5) = 0.932$

$V\ (SC_2 \geq SC_6) = 0.957$ $V\ (SC_2 \geq SC_7) = 0.945$ $V\ (SC_2 \geq SC_8) = 1$

The value for the third requirement is calculated as:

$V\ (SC_3 \geq SC_1) = 0.937$ $V\ (SC_3 \geq SC_2) = 1$ $V\ (SC_3 \geq SC_4) = 0.997$

$V\ (SC_3 \geq SC_5) = 1$ $V\ (SC_3 \geq SC_6) = 1$ $V\ (SC_3 \geq SC_7) = 1$

$V(SC_3 \geq SC_8) = 1$

The value for the fourth requirement is calculated as:

$V\ (SC_4 \geq SC_1) = 0.944$ $V\ (SC_4 \geq SC_2) = 1$ $V\ (SC_4 \geq SC_3) = 1$

$V(SC_4 \geq SC_5) = 1$ $V\ (SC_4 \geq SC_6) = 1$ $V\ (SC_4 \geq SC_7) = 1$

$V\ (SC_4\ \geq\ SC_8) = 1$

The value for the firth requirement is calculated as:

$V\ (SC_5 \geq SC_1) =$ 0.924 $V\ SC_5 \geq SC_2) = 1$ $V\ (SC_5 \geq SC_3) =$ 0.995

$V(\ SC_5 \geq SC_4)$ = 0.992 $V\ (SC_5 \geq SC_6)$ = 1 $V\ (SC_5 \geq SC_7) = 1$

$V\ (SC_5 \geq SC_8) = 1$

The value for the sixth requirement is calculated as:

$V\ (SC_6 \geq SC_1) =$ 0.9023 $V\ (SC_6 \geq SC_2) = 1$ $V\ (SC_6 \geq SC_3)$ = 0.845

$V\ (SC_6 \geq SC_4) = 0.972$ $V\ (SC_6 \geq SC_5) = 0.979$ $V\ (SC_6 \geq SC_7)$ =0.990

$V\ (SC_6 \geq SC_8) = 1$

The value of the seventh requirement is calculated as:

$V\ (SC_7 \geq SC_1) =$ 0.916 $V\ (SC_7 \geq SC_2) = 1$ $V\ (SC_7\ \geq SC_3) =$ 0.985

$V\ (SC_7\ \geq SC_4) =$ 0.983 $V\ (SC_7 \geq SC_5) = 0.989$ $V\ (SC_7 \geq SC_6)$ = 1

$V\ (SC_7 \geq SC_8) = 1$

The value for the eight requirement is calculated as:

$V\ (SC_8 \geq SC_1) =\ 0.831$ $V\ (SC_8 \geq SC_2) = 0.976$ $V\ (SC_8 \geq SC_3) =$ 0.911

$V\ (SC_8 \geq SC_4) =\ 0.907$ $V\ (SC_8 \geq SC_5) =\ 0.915$ $V\ (SC_8 \geq SC_6) =$ 0.938

$V\ (SC_8 \geq SC_7)$ = 0.927

The minimum degree of possibility of the superiority of each criterion over another is obtained with the help of Eqs.16 and 17 of the extent analysis method. The priority weights for the eight criteria are calculated as follows:

$d'(SC_1)$ = min $V\ (SC_1 \geq SC_2, SC_3, \ldots .SC_8)$ = min (1.00, 1.00, 1.00, 1.00, 1.00, 1.00, 1.00) = 1.00

Similarly,

$d'(SC_2)$ = min (0.841, 0.927, 0.923, 0.932, 0.957, 0.945, 1.00) = 0.841

$d'(SC_3)$ = min (0.937, 1.00, 0.997, 1.00, 1.00, 1.00, 1.00) = 0.937

$d'(SC_4)$ = min (0.944, 1.00, 1.00, 1.00, 1.00, 1.00, 1.00) = 0.944

$d'(SC_5)$ = min (0.924, 1.00, 0.995, 0.992, 1.00, 1.00, 1.00) = 0.924

$d'(SC_6)$ = min (0.902, 1.00, 0.845, 0.972, 0.979, 0.990, 1.00) = 0.845

$d'(SC_7)$ = min (0.916, 1.00, 0.985, 0.983, 0.989, 1.00, 1.00) = 0.916

$d'(SC_8)$ = min (0.831, 0.976, 0.911, 0.907, 0.915, 0.938, 0.927) = 0.831

Then the weight vector is defined as

$W' = (1.00, 0.841, 0937, 0.944, 0.924, 0.845, 0.916, 0.831)^T$

Using the extent analysis method, the normalised value of this vector decides the priority weights of each criterion over another. Therefore, normalised weight vectors of $C_{1,}$ C_2 C_3 C_4 C_5 C_6 C_7 C_8 are calculated as follows.

$(0.137, 0.115, 0.128, 0.13, 0.127, 0.124, 0.126, 0.114)^T$

The sub-criteria are compared separately under each criterion, and their priority weight is established using the same technique as before.

Each criterion's and sub-criterion's relative priority weight are determined at this point. The outcomes of the instance are displayed in Table 5. This hierarchy is deemed appropriate as each level's consistency is less than 0.1.

Table 5: Priority and consistency ratios for benchmarking performance of IWT

Criterion	Priority of criterion	Sub-Criterion	Priority of Sub-criterion	CR of sub-criteria
		S_1	0.168	
		S_2	0.181	
		S_3	0.154	
C1	0.137	S_4	0.172	0.016
		S_5	0.165	
		S_6	0.16	
		S_7	0.264	
		S_8	0.26	
C2	0.115	S_9	0.21	0.93
		S_{10}	0.266	
		S_{11}	0.207	
		S_{12}	0.229	
C3	0.128	S_{13}	0.213	0.021
		S_{15}	0.193	
		S_{16}	0.158	
		S_{17}	0.154	
		S_{18}	0.14	
		S_{19}	0.15	
C4	0.13	S_{20}	0.136	0.023
		S_{21}	0.143	
		S_{22}	0.137	
		S_{23}	0.14	
		S_{24}	0.193	
		S_{25}	0.221	
C5	0.127	S_{26}	0.177	0.034
		S_{27}	0.224	
		S_{28}	0.185	
		S_{29}	0.234	
		S_{30}	0.159	
C6	0.124	S_{31}	0.225	0.01
		S_{32}	0.187	

		S_{33}	0.194	
		S_{34}	0.219	
		S_{35}	0.266	
C7	0.126	S_{36}	0.294	0.003
		S_{37}	0.222	
		S_{38}	0.146	
		S_{39}	0.127	
		S_{40}	0.14	
C8	0.114	S_{41}	0.17	0.03
		S_{42}	0.137	
		S_{43}	0.151	

Source: Authors' work

6.3. Results and Discussion

The significant performance factors that could potentially impede the efficient functioning of the IWT are often difficult to pinpoint. However, the fuzzy AHP method, with its systematic approach, offers a solution. Prioritising these elements ensures a comprehensive understanding of IWT's performance. The implementation of the fuzzy AHP method will raise the performance measurement standards in the IWT, thereby boosting the efficiency of the transport system. The eight main categories of performance indicators associated with IWT, each crucial for a comprehensive understanding of IWT's performance, include: mobility and reliability, efficiency and profitability, environmental impact and decarbonisation, infrastructure condition, safety and security, economic development, innovative transport technology, and policy formulation and implementation for IWT. These categories encompass the critical aspects of performance in transport, logistics, and general performance measurement systems, providing a solid foundation for this research.

The results indicated that mobility, reliability, and infrastructure conditions are the most pressing factors affecting the efficiency of the IWT. This finding underscores the urgent need for stakeholders and policymakers to concentrate their efforts on these areas, ensuring that their processes and actions within the IWT domain are efficient and effective.

6.3.1. Mobility and reliability:

In this category, navigability is considered the most crucial factor in waterway transportation, affecting vessel cargo capacity and draught. Water depths directly affect the weight or volume of goods transported Regular dredging and channel maintenance are essential for safely passing vessels with drafts over three meters, ensuring waterway cleanliness and environmental sustainability (Beyer, 2018). Therefore, policymakers should enhance navigation channels through dredging and large-scale construction projects, while also implementing efficient sediment control strategies to mitigate the impact of topography, traffic, and infrastructure. On the other hand, prioritizing investment in enhancing navigability is crucial for the sustainability and operational efficiency of the IWT system, enabling realising its full potential and supporting sustainability objectives. Carriage capacity is ranked second within this group. Our work shows that carriage capacity is crucial for a vessel's productivity and profitability, enabling larger quantities of goods to be transported in a single trip. This leads to cost savings, improved customer service, and reduced transportation expenses. However, increasing carriage capacity can pose challenges like deeper navigation channels and sufficient port infrastructure. Stakeholders should invest in infrastructure development and maintenance. The timeliness of transit is vital for maintaining the competitiveness of IWT since it directly affects supply chains, the global economy and environmental factors. IWT can move large volumes of goods with minimal environmental impact, but delays can disrupt manufacturing and cause financial setbacks. Efficient management of travel time is essential for creating a suitable system and ensuring sustainable vessel schedules. Hence, it is recommended that policymakers should allocate resources towards technical innovations, partnerships, and automated locks.

6.3.2. Efficiency and profitability:

The study examines efficiency and profitability in the IWT sector, focusing on factors like total cost, energy efficiency, transport system attractiveness, and price alternatives. Price is the most crucial in this subcategory, as it reflects financial implications and can reveal inefficiencies. According to Konstantinos and Nektarios (2021), prices are a crucial factor in the marketplace and play an essential role in customers buying freight transport services. High costs in IWT can indicate outdated infrastructure or ineffective routing strategies, leading to environmental impacts. By observing price trends, stakeholders can identify areas for improvement, promoting a more sustainable industry. The study reveals that price alternatives, including freight transportation rates, significantly influence shipping efficiency, emphasizing the need for cost-effective and high-quality transportation modes. River Fright's total cost and expense are ranked second in this group.

River Fright's total cost and expense are crucial for evaluating financial performance in the IWT sector. The study shows that monitoring these metrics helps identify areas for cost reduction and operational efficiency. Therefore, stakeholders are encouraged to observe these metrics to identify areas where operational efficiency can be enhanced, such as by investing in more fuel-efficient technologies. The cost breakdown facilitates the assessment of suppliers' performance by finding discrepancies in costs, service quality, and reliability. The next in line is energy efficiency. This measures the number of services obtained relative to the amount consumed, aiming to control and limit energy usage to enhance productivity and avoid wastage, while preserving the economy, society, and environment (Golaka et al., 2022).

6.3.3. Environmental impact and decarbonization:

The study reveals that renewable and alternative energy are the most significant priority, followed by incentives and funding for emission reduction, enforcement/monitoring, and noise. The transport sector is responsible for the majority of GHG emissions in the EU and UK. Renewable energy sources can reduce environmental impact and promote a more environmentally friendly IWT system. However, initial costs and funding are required (Kalajdzic et al., 2022). Stakeholders are encouraged to explore sustainability funds and emission reduction models. Emission reduction is another critical aspect of performance in IWT, with the industry's significant role in generating GHGs and its negative impact on air quality and maritime well-being. Stricter emission regulations, resource allocation to advanced technologies, and partnerships can expedite the shift toward a greener IWT industry. Regulatory enforcement and monitoring systems are crucial for safety in IWT operations (Okuma and Enughwure, 2022). Monitoring systems are essential for evaluating adherence, detecting hazards, and improving effectiveness and reliability. Therefore, stakeholders should understand the intelligence methods employed to monitor safety and security threats to develop sustainable practices. To mitigate noise pollution, firms should invest in innovative technologies like quitters' propulsion systems and engine designs.

6.3.4. Infrastructure condition:

The study findings highlight the importance of improving connectivity, fleet modernisation, infrastructure maintenance, transhipment facilities, and limited geographical expansion in IWT for operational efficiency, capacity utilisation, safety, and energy efficiency. The study emphasizes the importance of improving connectivity, fleet modernisation, infrastructure maintenance, transhipment facilities, and geographical expansion in International Waterways (IWT) for operational efficiency, capacity utilization, safety, and energy efficiency. Enhancing connectivity improves operational efficiency, capacity utilisation, safety, and energy efficiency in IWT (de Langen et al., 2017). Waterway routes play a vital role in enhancing port-hinterland connectivity as well as promoting sustainable freight transport. Nevertheless, the findings from our study reveal that several factors affect the efficiency of IWT connectivity, including the quality of port infrastructure, locks, the availability of vessels, and the coordination between IWT and other forms of transportation. Ports are vital for global commerce, and advanced infrastructure improves connectivity, reducing congestion (Puhar, 2022). The finding shows that integrated transport networks enhance competitiveness, economic development, and sustainable growth in IWT networks. Policymakers must understand connectivity dynamics for informed decisions and investments in the industry. On the other hand, modern fleets are crucial for competitiveness and efficiency in waterways activities. Our findings reveal that innovative technology like automated cargo handling systems optimizes transportation, reduces turnaround times, and reduces operational expenses. Advanced communication systems and navigational aids improve safety. Infrastructure maintenance is a priority for IWT operations, as poorly maintained infrastructure can reduce reliability and operational expenses (Meersman et al., 2020). Therefore, authorities and operators should prioritize infrastructure maintenance and invest in eco-friendly materials.

6.3.5. Safety and security:

Seaworthiness is vital to maritime transportation, impacting vessel safety, effectiveness, and reliability (Zhang and Philips, 2015). Our study underscores that adherence to seaworthiness requirements is a guarantee of safe navigation, reduced accidents, adherence to timetables and completion of voyages within predicted timeframes, which is particularly beneficial for shipping firms and logistics providers. The findings from this study align with the work of Fulconis and Lissillour (2021), which emphasised that seaworthy ships can safely transport various types of cargo, maintaining the security and integrity of the goods while en route. Adherence upholds trust and confidence in the maritime business, urging stakeholders to prioritize and promote a safer, efficient, and sustainable IWT system. Navigation safety and route capacity are crucial for the efficient functioning of the IWT system (Hesselbarth et al., 2020). These factors include safe passage of vessels, installation of navigational aids, and adherence to speed limits and traffic regulations. Collaboration between government agencies, waterway authorities, port operators, and vessel owners is encouraged to improve navigation safety and ensure safe vessel operations. Traffic conditions, including vessel turnaround times, berth occupancy rates, and port congestion levels, are crucial metrics for identifying bottlenecks and inefficiencies. Effective monitoring helps port authorities identify capacity limitations and implement measures to enhance efficiency and port competitiveness, ultimately improving overall system performance.

6.3.6. Innovative transport technology:

In this category, the study highlights the importance of real-time information availability in the supply chain for efficient IWT operations. ICT tools like GPS, RIS tracking, and IoT devices enhance transport information access, decision-making, route planning, and risk mitigation. Our study findings underscore the importance of efficient communication among all stakeholders for seamless operations. Therefore, stakeholders should invest in digital tools to collect and analyze data, identify bottlenecks, and improve safety and security. This can enhance operations, foster collaboration, and stimulate innovation in the IWT sector. The next line in this category is hierarchical tracking and data tracing at the logistic unit level. These are crucial metrics in the IWT domain that enhance real-time visibility, transparency, and security. They help monitor ship and container movements, detect delays, and improve operations. These systems also provide vital information on vessel performance, fuel usage, and maintenance needs, reducing expenses and enhancing operational efficiency. Voyage planning is crucial for IWT's future and global economy viability. The findings from our study indicate that the voyage planning process involves optimizing routes, arranging cargo stowage, and ensuring regulatory compliance. Factors like weather, traffic, and port accessibility influence route planning. Innovative technologies and data analysis enhance cargo stowage while adhering to laws showcasing industry norms and public safety.

6.3.7. Economic development:

The IWT sector's economic development is primarily driven by employment, transportation system development, marketing, and aggregated added value. The shipping services sector significantly impacts global trade, volumes, consumer consumption habits, and industrial production. A growing job market benefits local economies, fosters ethical corporate practices, and reduces social disparity, allowing for policy actions and strategic investments. The transportation system's development ranked second in this group. Transport is acknowledged as a crucial element in economic progress, and IWT has significantly promoted economic growth and development in its operational regions (Lenz et al., 2018; Šev˘ceko-Kozlovska and Cižiuniene, 2022). Measures like shipping volume, capacity utilization, GDP growth rate, and gross investments can help stakeholders identify development opportunities and make informed decisions for IWT's expansion in a rapidly changing global economy. Marketing is crucial for businesses moving goods by waterways, as it helps attract and retain customers, increase market visibility, and enhance revenue and profitability (Kaup and Wiktorowska-Jasik, 2018). The finding from this study indicates that customized advertising campaigns and loyalty programs can draw in new customers and retain existing ones. Analyzing market trends and competitors' strategies helps develop unique services.

6.3.8. Policy formulation and implementation for IWT:

The study emphasizes the importance of sustainable development and environmental conservation in IWT, which has become increasingly reliant on maritime access due to globalized trade. It calls for robust policies to regulate and monitor this sector, ensuring economic viability and environmental responsibility. Under this category, knowledge transfer and best practices have the highest priority. These metrics are crucial performance metrics for IWT, promoting learning, efficiency, and sustainability (Pinto et al., 2019). The results further revealed that implementing best practices in vessel design, maintenance, safety rules, training programs, and emergency response protocols ensures safety and reliability. However, the industry's dynamic nature necessitates continuous updates and adaptations. The next priority within this group is education and training. Our study corroborated the study of Turcanu et al. (2021) which highlights the importance of education and training in optimizing the performance of IWT systems. These results affirm the essential role of education and training in optimising the performance of IWT. It emphasizes the need for continuous education and training to equip professionals with specialized knowledge, practical skills, and dedication to ongoing learning. This includes training in ship/barge handling, navigation, cargo management, and communication protocols. This outcome suggests that in order for the sector to function efficiently, stakeholders need to acknowledge the importance of continuous education as a vital component for professionals to keep up with industry trends and respond to evolving environments. This investment fosters a positive workplace culture, improving efficiency, safety, and overall industry performance. Administrative support is crucial for the transition to waterways systems, which are sustainable transportation alternatives that reduce greenhouse gas emissions, ease traffic congestion, and promote economic growth (Grezelakowski, 2019). This support is essential for advancing and maintaining waterways infrastructure, securing financial resources, and coordinating activities with other transportation modalities. It also fosters awareness and educational initiatives, facilitating collaboration among private sector entities, government bodies, and advocacy organizations, ultimately enhancing the effectiveness of IWT.

6.4. TOPSIS Method

According to the first phase of the TOPSIS method, each element is normalised using step II. Table 6 presents the decision matrix, while Table 7 illustrates the normalised decision matrix used for the TOPSIS analysis. Subsequently, the weighted normalised matrix, depicted in Table 8, is generated by multiplying each entry by its corresponding weight. The positive ideal solution (PIS) and the negative ideal solution (NIS) are established by identifying the maximum and minimum values in each column of weighted normalised decision matrix, as shown in Table 9. The Euclidean distance between the PIS and the NIS is calculated by assessing the distance between the alternative and the ideal solution, as outlined in Eq. 25 and displayed in Table 10. The ideal alternative is identified by ranking the computed values in descending order, with the highest value of Ci (closest to 1) indicating the best option. The relative proximity of each alternative to the ideal solution, along with their ranking is summarised in Table 11 with an illustration in Figure 7 showing the Ci value.

Table 6: Decision matrix

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18	S19	S20	S21	S22	S23	S24	S25	S26	S27	S28	S29	S30	S31	S32	S33	S34	S35	S36	S37	S38	S39	S40	S41	S42	S43
France (Seine Gateway)	1.8125	2.4375	1.625	1.8125	1.5	1.625	1.625	1.625	2	2.0625	1.8125	1.875	2.0625	1.875	1.75	2.4375	1.875	1.625	1.875	1.6875	1.75	1.4375	2.0625	1.9375	1.8125	2.1875	1.6875	2.1875	1.875	2.125	2.375	2.375	1.8125	2.125	1.875	2.3125	2.0625	1.5625	2.3125	1.75	1.875	2	2.1875
Netherlands (Rotterdam Gateway)	2.4375	2.6875	2.4375	2.4375	2.25	2.5625	2.0625	2.25	2.5s	2.5625	2.375	2.0625	2.25	2.1875	2.4375	2.5625	2.0625	2.3125	2.25	2.25	2.375	2.4375	2.625	2.4375	2.4375	2.5	2.4375	2.25	2.0625	2.25	2.25	2.75	2.6875	2.4375	2.125	2.5625	2.4375	2.375	2.5	2.125	2.4375	2.75	2.1875
Germany (Hamburg Gateway)	2.625	2.4375	2.5625	2.3125	2.5	1.8125	2.5	2.4375	2.125	1.9375	2.375	2.3125	2.125	2.25	2.5625	1.8125	2.25	2	2.6875	1.6875	1.8125	2.1875	2.625	2.25	2.0625	2	2.875	2.125	2.0625	2.25	2.125	2.5625	1.9375	1.9375	2.1875	2.125	2.125	1.75	2.0625	2.3125	2.0625	1.9375	2.125
Belgium (Antwerp Gateway)	1.875	2.0625	1.8125	2.0625	2.0625	1.75	1.875	1.9375	1.75	2	2.25	2.0625	2.4375	2.125	2.0625	2.5625	2.125	2.0625	1.875	2.1875	2	1.6875	2.3125	2.1875	2.4375	2	1.9375	1.8125	2	2.1875	1.9375	1.9375	1.8125	1.8125	1.75	2.25	1.9375	1.5625	2.3125	2.125	2	2.125	1.75
UK (Thames/Liverpool/Manchester Gateway)	1.5625	1.9375	1.5	1.9375	2	1.6875	1.75	1.625	1.5	1.5625	1.5	1.75	1.6875	1.3125	1.25	1.5625	2	1.6875	1.5625	1.5625	1.625	1.1875	1.5625	1.6875	1.5625	1.4375	2	1.5	1.6875	1.625	1.375	1.625	1.6875	1.6875	1.75	1.5	1.5625	1.375	1.875	1.4375	1.25	1.5625	1.5

Source: Authors' work

Table 7: Normalised decision matrix

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18	S19	S20	S21	S22	S23	S24	S25	S26	S27	S28	S29	S30	S31	S32	S33	S34	S35	S36	S37	S38	S39	S40	S41	S42	S43
France (Seine Gateway)	0.386	0.468	0.357	0.381	0.321	0.379	0.366	0.363	0.446	0.45	0.387	0.415	0.434	0.424	0.378	0.489	0.406	0.372	0.402	0.398	0.405	0.348	0.406	0.409	0.388	0.476	0.339	0.49	0.432	0.452	0.52	0.464	0.401	0.471	0.431	0.475	0.451	0.397	0.465	0.396	0.427	0.424	0.497
Netherlands (Rotterdam Gateway)	0.519	0.516	0.536	0.513	0.482	0.597	0.464	0.503	0.558	0.559	0.508	0.456	0.473	0.494	0.527	0.515	0.446	0.529	0.482	0.531	0.55	0.59	0.517	0.515	0.521	0.544	0.489	0.504	0.475	0.479	0.493	0.538	0.595	0.54	0.488	0.526	0.533	0.604	0.503	0.481	0.555	0.583	0.497
Germany (Hamburg Gateway)	0.559	0.468	0.563	0.487	0.535	0.423	0.563	0.545	0.474	0.423	0.508	0.512	0.447	0.508	0.554	0.364	0.487	0.458	0.576	0.398	0.42	0.53	0.517	0.475	0.441	0.435	0.577	0.476	0.475	0.479	0.465	0.501	0.429	0.43	0.503	0.436	0.465	0.445	0.415	0.524	0.47	0.411	0.482
Belgium (Antwerp Gateway)	0.399	0.396	0.399	0.434	0.442	0.408	0.422	0.433	0.391	0.436	0.481	0.456	0.512	0.48	0.446	0.515	0.46	0.472	0.402	0.516	0.463	0.409	0.455	0.462	0.521	0.435	0.389	0.406	0.46	0.466	0.424	0.379	0.401	0.402	0.402	0.462	0.424	0.397	0.465	0.481	0.456	0.45	0.397
UK (Thames/Liverpool/Manchester Gateway)	0.333	0.372	0.33	0.408	0.428	0.393	0.394	0.363	0.335	0.341	0.321	0.387	0.355	0.296	0.27	0.314	0.433	0.386	0.335	0.368	0.376	0.288	0.307	0.357	0.334	0.313	0.402	0.336	0.388	0.346	0.301	0.318	0.374	0.374	0.402	0.308	0.342	0.35	0.377	0.325	0.285	0.331	0.341

Source: Authors' work

Table 8: Weighted normalised matrix

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18	S19	S20	S21	S22	S23	S24	S25	S26	S27	S28	S29	S30	S31	S32	S33	S34	S35	S36	S37	S38	S39	S40	S41	S42	S43
France (Seine Gateway)	0.065	0.085	0.055	0.066	0.053	0.061	0.097	0.094	0.094	0.12	0.08	0.095	0.092	0.082	0.06	0.075	0.057	0.056	0.055	0.057	0.056	0.049	0.078	0.09	0.069	0.107	0.063	0.115	0.069	0.102	0.097	0.09	0.088	0.125	0.127	0.105	0.066	0.05	0.065	0.067	0.059	0.064	0.065
Netherlands (Rotterdam Gateway)	0.087	0.093	0.083	0.088	0.079	0.096	0.123	0.131	0.117	0.149	0.105	0.104	0.101	0.095	0.083	0.079	0.062	0.079	0.066	0.076	0.075	0.083	0.1	0.114	0.092	0.122	0.091	0.118	0.075	0.108	0.092	0.104	0.13	0.144	0.144	0.117	0.078	0.077	0.07	0.082	0.076	0.088	0.065
Germany (Hamburg Gateway)	0.094	0.085	0.087	0.084	0.088	0.068	0.149	0.142	0.1	0.112	0.105	0.117	0.095	0.098	0.088	0.056	0.068	0.069	0.078	0.057	0.058	0.074	0.1	0.105	0.078	0.098	0.107	0.111	0.075	0.108	0.087	0.097	0.094	0.114	0.148	0.097	0.068	0.056	0.058	0.089	0.064	0.062	0.063
Belgium (Antwerp Gateway)	0.067	0.072	0.061	0.075	0.073	0.065	0.111	0.113	0.082	0.116	0.1	0.104	0.109	0.093	0.07	0.079	0.064	0.071	0.055	0.074	0.063	0.057	0.088	0.102	0.092	0.098	0.072	0.095	0.073	0.105	0.079	0.073	0.088	0.107	0.118	0.103	0.062	0.05	0.065	0.082	0.062	0.068	0.052
UK (Thames/Liverpool/Manchester Gateway)	0.056	0.067	0.051	0.07	0.071	0.063	0.104	0.094	0.07	0.091	0.066	0.089	0.076	0.057	0.043	0.048	0.061	0.058	0.046	0.053	0.052	0.04	0.059	0.079	0.059	0.07	0.074	0.079	0.062	0.078	0.056	0.062	0.082	0.1	0.118	0.068	0.05	0.044	0.053	0.055	0.039	0.05	0.044

Source: Authors' work

Table 9: The positive and negative ideal value

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18	S19	S20	S21	S22	S23	S24	S25	S26	S27	S28	S29	S30	S31	S32	S33	S34	S35	S36	S37	S38	S39	S40	S41	S42	S43
Positive ideal	0.094	0.093	0.087	0.088	0.088	0.096	0.149	0.142	0.117	0.149	0.105	0.117	0.109	0.098	0.088	0.079	0.068	0.079	0.078	0.076	0.075	0.083	0.1	0.114	0.092	0.122	0.107	0.118	0.075	0.108	0.097	0.104	0.13	0.144	0.148	0.117	0.078	0.077	0.07	0.089	0.076	0.088	0.065
Negative ideal	0.056	0.067	0.051	0.066	0.053	0.061	0.097	0.094	0.07	0.091	0.066	0.089	0.076	0.057	0.043	0.048	0.057	0.056	0.046	0.053	0.052	0.04	0.059	0.079	0.059	0.07	0.063	0.079	0.062	0.078	0.056	0.062	0.082	0.1	0.118	0.068	0.05	0.044	0.053	0.055	0.039	0.05	0.044

Source: Authors’ work

Table 10: Distance to positive and negative ideal points

	Distance to positive ideal	Distance to negative ideal
France (Seine Gateway)	0.161	0.119
The Netherlands (Rotterdam Gateway)	0.042	0.222
Germany (Hamburg Gateway)	0.096	0.186
Belgium (Antwerp Gateway)	0.14	0.131
UK (Thames/Liverpool/Manchester Gateway)	0.235	0.023

Source: Authors’ work

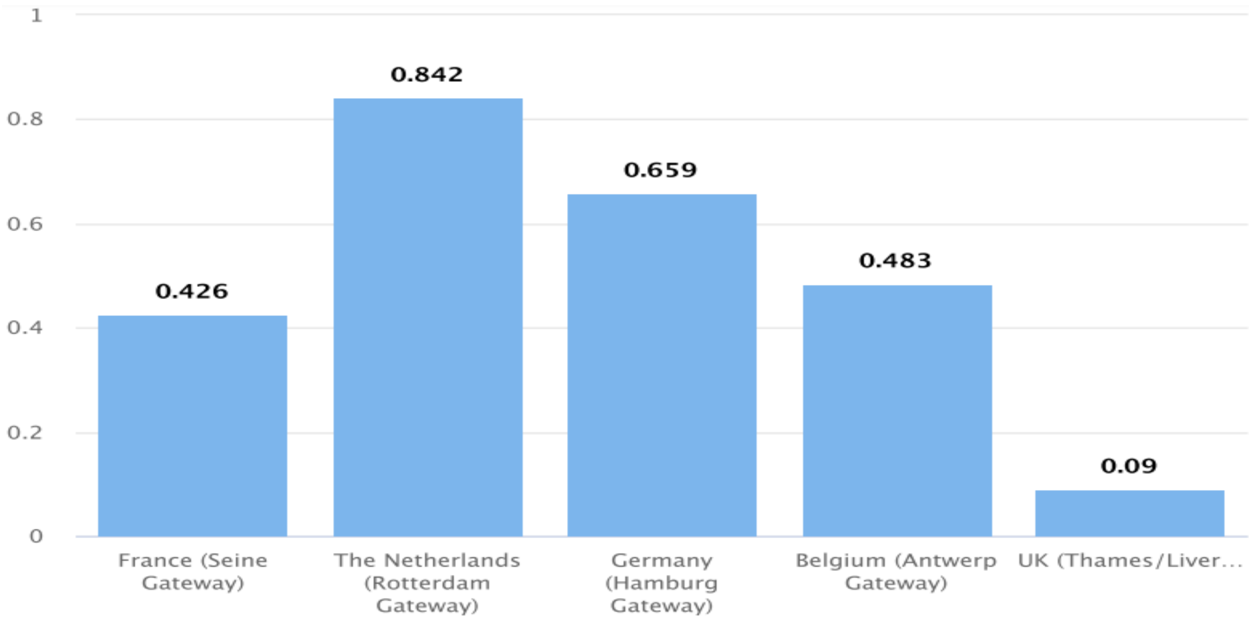

Figure 7: The shows Ci value

Source: Authors’ work

Table 11: The C_i value and ranking

	C_i	Rank
France (Seine gateway)	0.426	4
The Netherlands (Rotterdam gateway)	0.842	1
Germany (Hamburg gateway)	0.659	2
Belgium (Antwerp gateway)	0.483	3
UK (Thames/Liverpool/Manchester gateway)	0.09	5

Source: Authors’ work

As shown in Figure 7, The Netherlands (Rotterdam gateway) has the highest performance in terms of freight transportation via waterways (closeness coefficient 0.842), followed by Germany (Hamburg gateway), with a closeness coefficient of 0.842, Belgium (Antwerp gateway) came third with a closeness coefficient 0.483, next was France (Seine gateway) with a closeness coefficient of 0.426 and the least among this gateways was the UK (Thames/Liverpool/Manchester) with a distance closeness coefficient of 0.09. Statistics revealed that while the four European case study countries were high, the corresponding value for the UK regional gateways remained very low. The margin by which the Netherlands, Germany, Belgium, and France lead the UK shows how these countries and their strategic positioning have adapted inland shipping operations, aligning with the demands and dynamics of the global market. In this competitive business environment, decision-makers must possess a profound comprehension of the critical aspects influencing performance in the industry. This understanding is crucial for ensuring adequate improvement and underlines the urgency of the matter. From the UK perspective, the result illustrates the level of effort required to be done to promote and increase the performance of IWT in the future.

Shifts in transport systems are primarily influenced by supply conditions (e.g., infrastructure, innovations), demand factors (e.g., flow shifts), and regulation. However, the real game-changer could be technological advancements. These could lead to effective innovations such as digitalisation, automation, networking, renewable fuels, and electrification, offering a promising and optimistic future for the industry.

7. Research Implications.

This study explores performance characteristics and variables influencing perception of performance in inland waterway transport and logistics, providing insights for modelling and understanding its profound implications.

7.1. Theoretical contributions/implications

This study's theoretical contributions are of utmost importance in the field. The study complements the existing body of literature in IWT by providing a detailed overview of performance measures in the industry. This can serve as a groundwork for research in the domain of IWT by establishing a common understanding of measurement standards for internal and external comparison to ensure effective progress monitoring. The study proposed a system model that provides detailed insight into various elements influencing performance perception in the IWT sector. It consists of eight basic criteria categories and forty-three sub-categories derived from different kinds of performance in the IWT sector. This extensive performance classification model aids in identifying many potential performance factors, including internal and external to the IWT network, with varying degrees of influence. The study complies with a comprehensive list of potential performance elements that impact the eight main criteria outlined by integrating perspectives from academics and industry professionals. This will assist researchers, industry practitioners and all relevant authorities in the IWT domain in identifying and categorising specific performance elements related to a particular improvement scenario. It will also serve as a foundation for measuring the standard of the IWT performance index model to facilitate the widespread implementation of standardised performance metrics across the industry.

7.2. Managerial implications

This study employed empirical evidence to verify the effectiveness of the established fuzzy-AHP and TOPSIS approach. Therefore, several managerial implications are outlined. The proposed model is novel because it integrates the fuzzy AHP and TOPSIS models as part of an integrated methodology. This allows decision-makers' preferences to be taken into account when making strategic decisions about performance improvement on the IWT system. Furthermore, the uncertainty resulting from unknown data is taken into account by the model. Thus, applying fuzzy logic theory to practice can help firms quickly and efficiently address ambiguity and manage uncertainty in decision-making. This research contributes practically by performing empirical studies in the IWT sectors of the UK, France, the Netherlands, Germany, and Belgium to aid managers in making resource-effective and time-efficient decisions. Thus, the findings from this study can offer relevant firms or decision-makers with up-to-date information that accurately represents the current practices and status of the country's IWT sectors to ensure accurate decision-making and enhance competitiveness. The study findings allow stakeholders and decision-makers to anticipate and address potential performance factors using the IWT performance index model. However, the IWT connects the operational execution of pre- and post-waterway carriage transportation. In this study, performance metrics for pre- and post-carriage transportation are excluded as their values are not directly impacted by the system. However, the study thoroughly examines the critical performance factors involved in the physical execution of freight transport by waterways, procedures, and operations at the destination port. It utilises previous academic literature, direct observation, official reports and insight from relevant authorities and industry practitioners in various relevant positions within the IWT sector.

8. Conclusion

Globalisation and commercialization have significantly expanded the logistics chain, putting significant demands on intermodal transport networks. This has led to increased reliance on maritime access and inland waterways as supplementary transport. The integration of IWT players into modern logistics systems has resulted in a need for inland shipping to adapt and redefine its operations. The freight transportation industry emphasizes a well-functioning supply chain for customer satisfaction, cost reduction, and market competitiveness. The subject is gaining more attention and continues to be explored in academic literature. However, the extent of research on performance metrics related to IWT is quite limited, and the clear categorisation of performance factors, as well as other aspects that influence the perception of performance in the IWT domain, have yet to be empirically identified, examined, and prioritized. In this context, this study aims to provide a structured framework to identify and prioritize key elements influencing the overall performance of the IWT supply chain employing fuzzy-AHP and TOPSIS methodologies.

Increased competition is a common factor across all industries since it fosters better performance and a need for high-quality services. Thus, this research develops a comprehensive performance database tailored for stakeholders operating within the IWT domain. Experts typically offer subjective evaluations and are commonly uncertain in their scoring assessments. As a result, implementing the AHP approach in a fuzzy setting helped to lessen the influence of bias. The analysis of existing literature, along with contributions from experts, resulted in the identification of 48 distinct performance factors, which were categorised into eight different performance types. This research employs FAHP to prioritize the critical success factors, followed by the application of the TOPSIS techniques for their ranking. The finding reveals that mobility/reliability and infrastructure conditions are the most pressing factors affecting the efficiency of the IWT. This finding underscores the need for stakeholders and policymakers to concentrate their efforts on these areas, ensuring that their processes and actions within the IWT domain are efficient and effective. Stakeholders are encouraged to comprehend the essential factors that affect industry performance within the IWT sectors. Additionally, stakeholders must collaborate closely with governmental bodies to develop effective policies and foster trustworthy relationships, thereby facilitating the seamless functioning of the IWT supply chain.

The Netherlands, Germany, Belgium, France and the UK have been evaluated with reference to the identified critical success factors for necessary benchmarking with the Netherlands and Germany, having the highest performance in inland shipping via waterways. These results indicate that these countries have adapted their operational performance to align with the global market demands. This ranking will serve as a tool for stakeholders to enhance their performance in areas that are likely to impede the performance of the IWT supply chain from reaching its intended goals.

8.1. Limitation and future research

Various distinct performance factors can impact the performance of the intermodal IWT chain. A framework based on fuzzy AHP-TOPSIS has been developed to analyse the factors found in the literature study and expert input. The performance factors that have been identified have been prioritised in order of importance, providing a practical guide for decision-making and a roadmap for improving the efficiency of the IWT. Nevertheless, the authors note that the research had certain limitations. First, the research offers a comprehensive viewpoint confined to the European context. Secondly, specified professional occupations were the only ones included in the sample selection based on the study's inclusion criteria. The participants in this research possess extensive expertise in academia or substantial practical experience and occupy managerial positions or higher in professional domains. As a result, the sample size represents yet another study limitation. The respondents' professional knowledge, experience, and attitude are crucial components of the proposed system model and could introduce subjectivity. Respondent and their opinions or impressions could be influenced by the context in which they took part in the study's survey. Unforeseen variables, such as personal conflicts with firms or external influence, can affect their perspectives. Thus, this illustrates yet another way that this study is limited.

Future research endeavours should aim to expand upon the findings of this current study. The significance of this research is underscored by the potential for expanding our understanding of IWT performance by applying identical study processes to a different region. Since benchmarking is inherently a continuous process, this study can serve as a preliminary reference for future research. Additional research may consider exploring alternative multi-criteria decision-making (MCDM) techniques, such as the fuzzy analytic network process (ANP) or Vikor, in a fuzzy setting. The IWT system coordinates pre- and post-waterway carriage but does not directly influence these metrics. The findings of this study serve as a starting point for additional research centred on pre- and post-waterway carriage performance.

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