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Investigation of Urban Freight Logistics Performance in Smart Cities Using the Fuzzy AHP Method

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Abstract Urban freight logistics in smart cities is an interdisciplinary approach to logistics that seeks to maximize efficiency and sustainability in the movement of goods and services within these urban areas. As cities become more intelligent, urban freight logistics must adapt to handle problems including traffic, the environment, and last-mile delivery efficiency. The aim of this study is to identify the criteria that are important for urban freight logistics in smart cities. This study is unique because, to our knowledge, no quantitative research has been done on the subject, despite its significance. As a research method, the Fuzzy Analytical Hierarchy Process (Fuzzy AHP) methodology was used to determine the elements that are essential to the efficiency of urban freight logistics in smart cities. Transport engineering is the most crucial field for the performance of urban freight logistics in smart cities. Sustainability has been identified as the most crucial factor in evaluating the success of urban freight logistics in smart cities. By determining which factors are crucial, the results of this study will help develop more efficient methods for improving the performance of urban transport logistics in smart cities.

Keywords Smart Cities · Urban Freight Logistics · Project management · Analytic Hierarchy Process · Fuzzy Logic.

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The movement of goods within city centers, including delivery and pick-up, is called urban logistics (Machado et al., 2020). Interaction between suppliers and consumers has an important place in transport logistics, which enables the movement of goods from production to consumption (Mejia et al., 2019). Urban freight logistics activities create noise pollution, cause traffic congestion and increase carbon emissions (Muñoz-Villamizar et al., 2019). Therefore, the effective and efficient realization of urban freight activities affects the sustainability of smart cities. Urban logistics activities are increasing day by day, and this increase leads to accidents, environmental problems, and energy inefficiency (Nathanail et al., 2016; Ghaderi et al., 2022). Promoting improved transportation and cutting expenses are two aspects of the smart city approach to urban freight logistics. Smart city logistics encompasses crucial activities, including urban infrastructure provision, traffic and public transport management, land use planning, facility location, waste management, and inventory, transportation and storage (Pan et al., 2021). To achieve these objectives, smart cities utilize computing devices, such as smartphones, which gather real-time data and connect through the internet to exchange information with one another (Quijano-Sánchez et al., 2020). Urban transport logistics in smart cities is an element that contributes to the sustainability and efficiency of cities (Serrano-Hernandez et al., 2021). As a result of the fact that cities are becoming more and more crowded day by day and people are turning more and more toward e-commerce, the need for more efficient and effective execution of logistics activities has further strengthened (Digiesi et al., 2017). To meet this need, smart city technologies have become more and more frequently used day by day. The main ones are Internet of Things (IoT) sensors, big data analytics and artificial intelligence supported route optimization programs transportation (Buyukozkan and Mukul, 2019). Within these technologies, electric and autonomous vehicles have been used more frequently, and as a result, the carbon footprint in freight logistics is decreasing (Dohn et al., 2022). Micro-scale distribution centers and cargo bikes have contributed to more efficient and environmentally friendly last-mile deliveries (Reyes Rubiano et al., 2021). The creation of low-emission zones and the organization of smart loading and unloading areas have positive effects on city traffic and increase the efficiency of logistics operations (He and Haasis, 2020). Smart logistics projects designed and implemented by the public and private sectors acting together make the supply chain more environmentally friendly and integrated.

The aim of this study is to identify the criteria that are important for urban freight logistics in smart cities. Fuzzy AHP was used in the study. The fuzzy AHP makes it possible to convert hard-to-measure criteria into numerical values that are crucial for smart city transportation logistics. This study will identify the key challenges and opportunities in urban freight logistics in smart cities. The uniqueness of this study is that despite the importance of the topic (achieving full efficiency in the transport of goods and services in smart cities), no quantitative study has been conducted on this topic before, as far as it has been identified. Nathanail et al. (2016) estimated evaluation indicators for smart logistics solutions to be used in the decision-making of stakeholders related to urban freight logistics to achieve sustainable city logistics. In determining these evaluation indicators, a literature review was utilized. Golinska-Dawson and Setanan (2023) identified through a systematic literature review which innovations implemented by logistics service providers in sustainable urban transport are suitable to support the transition to energy-efficient smart cities. Pan et al. (2023) reviewed the state-of-the-art of smart cities for sustainable urban freight logistics, for which bibliometric analysis was performed. He and Haasis (2020) presented a theoretical research framework for future sustainable urban freight logistics for smart cities. By identifying the key elements of urban freight logistics in successful smart cities, this study will enable decision makers to develop strategies that promote logistics performance centered on these key elements. Consequently, the research questions (RQ) of this paper are presented as follows:

RQ 1. What is the most important discipline for urban freight logistics performance in smart cities?

RQ2. What is the most important criterion for the performance of urban freight logistics in smart cities?

Literature Review

With the globalization of the world, economic activities have increased the mobility of goods, and as a result of this increase, the use of vehicles has increased. With the increase in the use of transportation vehicles, problems such as environmental pollution and increased traffic have occurred, and researchers have turned to developing ideas and studies to solve these problems. One of the most important of these efforts has been smart city design. Smart city solutions have been developed in response to the negative externalities caused by transportation. This development phase has led to the creation and study of the concept of urban freight logistics in smart cities.

Smart City

The concept of smart cities encompasses various facets, including mobility, which pertains to the movement of people, goods, services, transportation, and information within the urban landscape (Buyukozkan and Ilicak, 2022). For a considerable duration, endeavors to establish smart cities have been associated with technological advancements (Correia et al., 2023). Smart cities act as a kind of urban development model (Angelidou, 2014). The development of smart cities has been frequently associated with nations that possess substantial urban centers and a high gross domestic product (GDP) (Correia et al., 2022). These cities today are a collection of highly interconnected cultures that actively welcome information and communication technologies (ICT) as an essential part of contemporary city infrastructure (Calzada and Cobo, 2015). However, discussing smart cities involves discussing more than simply technology; it also involves discussing something more intricate and human. The fact that cities are human settlements and are there to serve us should not be underestimated (Camero and Alba, 2019). The primary goal of smart cities is to provide its residents with a safer, healthier environment that enhances their quality of life (Dohn et al., 2022). In smart cities, the idea is to create a better learning environment by using or creating open data. Big data is being used in smart cities to help with remote vehicle control, route optimization, and pollution measurement (Serrano-Hernandez et al., 2021). Enabling companies, NGOs and citizens to empower themselves using open data contributes to the collective spirit of smart cities (Meijer and Bolívar, 2016). One possible area for major development in the framework of smart cities is the use of drones and tiny unmanned aerial vehicles (UAVs) (Kim et al., 2020).

Logistics in smart cities can be defined as a system that facilitates the incorporation of cutting-edge technologies in the organization and management of transportation (Buyukozkan and Mukul, 2019). Smart city logistics expects finding innovative solutions and models for freight utilization, the use of intelligent and integrated Transport Systems and Information Technologies (Xenou et al., 2022). Smart cities contribute to the improvement of urban freight logistics activities (Mejia et al., 2019). In addition to offering an effective delivery service, smart city logistics can lower CO_2 emissions and traffic congestion (Feng et al., 2021). It is necessary to study the interaction between improving freight distribution and smart city development and information communication technology (Russo and Comi, 2021). Smart logistics utilizes information technology to ensure effective information sharing, proper use of resources and professional customer service (Ahamd, 2019).

Urban Freight Logistics in Smart Cities

The main objective of urban logistics is to increase the efficiency of the supply chain by improving the activities of the transporters, service providers and consumers that make up the system (Rodrigue et al., 2017; Pan et al., 2021). By ensuring that commodities are distributed to retail, commercial, and residential institutions, urban freight logistics plays a crucial part in the economic development of cities (Cossu, 2016). Policymakers are responsible for ensuring the sustainability, safety, livability, and efficiency of urban freight logistics; they must strike the best possible balance to accomplish these objectives (Gatta et al., 2017). Organizing urban transportation operations promotes the growth of sustainable logistics (Arvidsson et al., 2016). However, the expansion of urban freight logistics has also led to a rise in large cities' noise levels, air pollution, and traffic congestion (Digiesi et al., 2017). Road congestion in city centers is a result of urban freight logistics (Kostadinovic and Savatkic, 2017). Given these obstacles, national and local policymakers are looking into ways to support sustainable urban freight logistics (Guerlain et al., 2019; Pan et al., 2021) and enforce strict laws on the entry of freight vehicles into urban areas to reduce social and environmental problems (Lu, 2014). Several important elements, such as journey distance, travel costs, and environmental externality, influence the effectiveness of urban freight logistics are (Gayialis et al., 2018). Urban consumers anticipate the timely delivery of their purchases (Lindawati et al., 2015; Reyes-Rubiano et al., 2021).

As the area that contributes most to the realization of ESG principles, the focus should be on intelligent city logistics solutions to meet the social development goals (Barykin et al., 2023). The success of smart cities in environmental sustainability depends on the environmental optimization of transport activities (Shee et al., 2021). The transportation of goods and services in urban areas is governed by urban freight logistics, which uses data-driven and technological solutions to maximize efficiency, minimize pollution and traffic, and improve sustainability (Pan et al., 2021). Improving the quality of life, preventing the factors that increase environmental pollution or reducing the pollution levels of these factors and solving traffic problems are the main goals of smart city initiatives (Buyukozkan and Ilicak, 2022). Therefore, smart technologies play an important role in smart cities. The use of technological tools such as drones, cargo bicycles and electric cars are elements that will contribute to the achievement of the goals of smart city initiatives (He and Haasis, 2020). Sustainable smart city activities, which require interdisciplinary efforts, depend on smart urban freight logistics (Lu, 2014). Smart cities need environmentally friendly vehicles (Reyes Rubiano et al., 2021). In urban freight logistics in smart cities, environmental concerns are very important due to the high delivery frequency, the need for delivery times, the weight of the cargo, and the increase in energy consumption and CO2 emissions in urban freight logistics (Navarro et al., 2016). Table 1 provides a comprehensive classification of the criteria that affect the performance of urban freight logistics in smart cities. A total of 25 sub-criteria were identified as a result of the literature review. The Scopus, Web of Sciences database was used to identify these criteria.

Table 1

Performance criteria for urban freight logistics in smart cities

Main Criterion	Code	Sub-Criteria	Authors
(A1) Environmental Science	(A1.1)	Environmentally friendly logistics activities	Nathanail et al, 2016; Buyukozkan and Ilıcak, 2022
	(A1.2)	Sustainability	Buyukozkan and Ilıcak, 2022; Cerrone and Sciomachen, 2022
	(A1.3)	Waste management efficiency	Dohn, 2022
	(A1.4)	Environmental pollution	Dohn, 2022; Korczak, 2019
	(A1.5)	Emission reduction	Dudek, 2022

Main Criterion	Code	Sub-Criteria	Authors
	(A1.6)	Transport mode use	He and Haasis, 2020; Kim et al., 2020; Russo, 2021
(A2)Transportation Engineering	(A2.1)	Traffic congestion reduction	Buyukuzkan and Ilıcak, 2022
	(A2.2)	Freight movement service effectiveness and speed	Buyukozkan and Mukul, 2019
	(A2.3)	Freight distribution improvement	Russo and Comi, 2021
	(A2.4)	Route planning optimization	Dudek, 2022; Korczak, 2019
	(A2.5)	Capacity sharing in the context of infrastructure and equipment sharing between different transport modes	Korczak, 2019
(A3)Economics	(A3.1)	Pricing impacts of new vehicle technologies on road systems	Buyukozkan and Ilıcak, 2022
	(A3.2)	Minimization of the route-related cost	Cerrone and Sciomachen, 2022
	(A3.3)	External costs of passenger and freight transport	Dohn, 2022
	(A3.4)	Transportation and logistics costs	Guimares et al., 2021
	(A3.5)	Resource and energy efficiency in the transportation of good	He and Haasis, 2020
(A4) Urban Planning	(A4.1)	Ideal traffic condition	Buyukozkan and Mukul, 2019
	(A4.2)	Expansion of organizations providing services related to the safety of citizens and freight movement	Dohn, 2022
	(A4.3)	Encouragement of smart technologies	Guimarães et al., 2021
	(A4.4)	Design of a flexible and sustainable urban freight logistics system	He and Haasis, 2020
	(A4.5)	Education, including activities such as teaching and encouraging safe and eco-driving	Korczak, 2019
	(A4.6)	Design of infrastructure and development of logistics facilities related to consolidation/distribution centers and logistics	Korczak, 2019
(A5) Information Technology	(A5.1)	Use/development of information technologies	Kim et al., 2020; Correia et al.,. 2021; Korczak, 2019
	(A5.2)	Use of big data related to transportation	Serrano-Hernandez et al., 2021
	(A5.3)	Remote controllability of vehicle	Serrano-Hernandez et al., 2021

Environmentally friendly logistics activities (A1.1): The impact of environmentally friendly practices on the efficiency of urban freight logistics in smart cities is multifaceted, encompassing the reduction of emissions, enhancement of efficiency, minimization of costs and promotion of sustainability (Nathanail et al., 2016). The frequency of such practices exerts a significant influence on the performance of urban freight logistics in smart cities.

Sustainability (A1.2): The regularity of sustainable transportation indicates sustainability, which in turn suggests favorable performance of urban transportation logistics in smart cities, as outlined by Cerrone and Sciomachen (2022). Smart cities are driven to ensure individual experience improved, secure and healthy lives, and hence, sustainability remains an integral component in achieving this goal.

Waste management efficiency (A1.3): Smart cities aspire to protect the environment while conducting eco-friendly urban logistics operations (Dohn et al., 2022).

Environmental Pollution: The issue of environmental pollution (A1.4) necessitates the implementation of initiatives that are meticulously designed to circumvent the occurrence of harmful environmental consequences (Dohn et al., 2022). The pernicious impact of pollution on the populace's well-being is indisputable. The emission of noxious pollutants by trucks can intensify atmospheric conditions and contribute to an escalation in respiratory illnesses.

Emission reduction (A1.5): Emission reduction is a necessary criterion for ensuring sustainability (Dudek and Kujawski, 2022). In order to ensure sustainability, companies conducting urban freight logistics activities should give importance to air cleanliness, reduce costs and increase efficiency.

Transport mode use (A1.6): Electric vehicles emit less greenhouse gases into the air than petrol vehicles (Kim et al., 2020). Delivery robots and drones may have less environmental impact than conventional delivery trucks.

Traffıc congestion reduction (A2.1): The efficiency of freight logistics in smart cities increases with the reduction of traffic congestion (Büyüközkan and Ilıcak, 2022). With the decrease in traffic, urban freight logistics moves faster, increasing production.

Freight movement service effectiveness and speed (A2.2): Optimizing delivery routes can increase consumer satisfaction, reduce operating costs, improve traffic flow and create a more positive environmental impact (Büyüközkan and Ilıcak, 2022).

Freight distribution improvement (A2.3): Increasing the functions of urban freight logistics can increase productivity and contribute to innovation and sustainability (Russo and Comi, 2021).

Route planning optimization (A2.4): By optimizing route planning, the speed and efficiency of freight logistics in smart cities can be increased and contribute to environmental sustainability. It can lead to lower costs and greater customer satisfaction in freight logistics (Korczak, 2019).

Capacity sharing in the context of infrastructure and equipment sharing between different transport modes (A2.5): Effective and efficient capacity sharing affects costs, contributes to infrastructure and equipment utilization management, and can positively affect traffic flow (Korczak, 2019). For example, if several companies are allowed to use a single warehouse, resources may be utilized more efficiently.

Pricing impacts of new vehicle technologies on road systems (A3.1): The design and construction of support equipment for new vehicle technologies (e.g. home charging stations, electric or hydrogen-powered vehicles) can increase costs. Urban freight logistics's environmental friendliness is impacted by new vehicle innovations (Buyukozkan and Ilıcak, 2022).

Minimization of route-related cost (A3.2): Delivery routes can be optimized to minimize route-related expenses (A3.2), which has been demonstrated to increase delivery efficiency and lower transit costs, therefore increasing the efficiency of urban freight logistics (Cerrone and Sciomachen, 2022). Additionally, it has been shown that reducing traffic speeds up deliveries and improves industrial performance. Urban freight carriers can limit air pollution by lowering route costs, and effective transportation and distribution routes have been shown to minimize emissions and improve fuel efficiency. The result of these factors is a reduction in delivery expenses, which in turn can increase customer satisfaction. Enhanced dependability and efficiency, in turn, enhance client satisfaction and promote service reuse.

External costs of passenger and freight transportation (A3.3): The external costs of passenger and freight logistics have been shown to have an impact on smart city urban freight mobility (Dohn, 2022). Furthermore, limitations on emissions and noise have been demonstrated to impede smart city urban freight mobility. The use of sustainable methods strengthens a company's reputation and appeals to eco-conscious customers.

Transportation and logistics costs (A3.4): The financial burden of urban haulage is influenced by logistics and transport expenditures (Guimares et al., 2021). Transportation enterprises should endeavor to curtail their logistics expenditures and enhance their services. The implementation of automation and artificial intelligence can reduce operational expenditure, enhance financial performance, and optimize corporate cost management, consequently leading to competitive pricing and enhanced profitability. Furthermore, the reduction of logistics expenditure can contribute to the enhancement of delivery speeds and accuracy.

Resource and energy efficiency in the transportation of goods (A3.5): The sustainability of urban freight logistics is susceptible to the costs associated with logistics; hence, investments in the efficiency of resources and energy in the transportation of products are imperative. The efficiency of resources and energy can reduce transport costs for companies, leading to savings for both firms and consumers. By increasing resource and energy efficiency, sustainable smart cities should seek to reduce the carbon footprint of urban freight logistics, claim He and Haasis (2020). Additionally, efficient transportation systems save product transit times and increase supply chain dependability.

Ideal traffic condition (A4.1): The ideal traffic condition (A4.1) is defined as a state of optimal traffic management in urban areas, characterized by the efficient movement of trucks and delivery vehicles, leading to reduced delivery times. By lowering accidents and traffic congestion, this condition improves pedestrian and driving safety (Buyukozkan and Mukul, 2019). The ability of trucks and delivery vehicles to move throughout cities is essential for minimizing wear and damage, which lowers maintenance costs and increases the vehicles' lifespan. Additionally, there is a chance that urban traffic management will improve freight logistics, save business expenses, and boost customer satisfaction.

Expansion of organizations providing services related to the safety of citizens and freight movement (A4.2): By continuously monitoring and modifying traffic lights and other traffic control systems, the growth of organizations offering services related to citizen safety and freight movement (A4.2) has the potential to speed up urban freight logistics (Dohn, 2022).Law enforcement and emergency response teams can also improve the safety of urban transportation by preventing accidents. To guarantee passenger safety, public transportation organizations can help with the upkeep and planning of the city's public transportation system. The expansion of roadways, the implementation of cycle lanes, and the enhancement of footpaths can bolster freight mobility. Collaborative efforts between urban transportation authorities can maximize and safeguard the conveyance of goods.

Encouragement of smart technology (A4.3): Such technology includes GPS tracing, route refinement, and computerized transportation systems (Guimarães et al., 2021). The refinement of transportation routes mitigates delivery delays and traffic congestion. The use of intelligent technology to oversee and conduct cargo vehicle operations enables logistics companies to swiftly identify and handle traffic congestion, vehicle malfunctions, and unforeseen interruptions. The proficiency and dependability of freight transport expedites delivery. Electric and alternative fuel vehicles can make urban freight logistics more environmentally sustainable, whilst utilizing technology can assist cities in reducing the ecological effects of freight logistics. Smart technology can produce considerable freight logistics data for model analysis, enhancing route design, vehicle management and transport systems. Simultaneously, traffic, weather, and barrier data extracted from smart technologies can bolster safety in urban freight logistics.

Design of a flexible and sustainable urban freight logistics system a sound and flexible urban freight logistics system (A4.4): The success of electric, autonomous cars and drones is dependent on sustainable transport infrastructure, which can ultimately improve urban freight logistics and decrease environmental harm. Data-driven decision-making is vital in developing flexible transport systems, and metropolitan regions analyze transport patterns, traffic flows and other characteristics to optimize transport networks and urban freight logistics.

Education including activities such as teaching and encouraging safe and eco-driving (A4.5): It has been demonstrated that the implementation of eco-friendly driver training can enhance urban transport safety and efficiency (He and Haasis, 2020). Drivers who adhere to proper safety and environmental procedures are less prone to accidents and more efficient in driving. Consequently, they can drive in a way that reduces accidents and improves the transport infrastructure.

Design of infrastructure and development of logistics facilities related to consolidation/distribution centers and logistics (A4.6): The development of infrastructure related to the design, construction, and development of consolidation and distribution centers and logistics facilities is expected to reduce transport costs by decreasing loading and unloading times at well-designed centers. Consistent with this goal, consolidation facilities that combine goods from various carriers can help reduce delivery frequency and increase operational efficiency, as noted by Korczak (2019). Urban transportation congestion can also be reduced by storing freight in logistics and distribution facilities. Efficiency gains could result from the incorporation of automation, robots, and Internet of Things devices into distribution center-based logistics and transportation operations. Additionally, these hubs enable transportation companies to use rail or water for longer distances. Urban freight logistics can benefit from the integration of data exchange platforms, last-mile distribution networks, traffic management systems, logistics facilities, and distribution centers into the smart city infrastructure.

Use/development of information technologies (A5.1): By helping businesses optimize delivery routes, these technologies could lower fuel use and enhance time management (Korczak, 2019). One such technology that allows businesses to precisely monitor shipments, troubleshoot problems, and meet client expectations is simultaneous tracking systems. Instant updates positively affect customer satisfaction in terms of creating the perception that the customer is cared about in terms of business and service (Korczak, 2019). Technologies such as GPS increase shipment safety. Finding the best routes can provide positive improvements in time, fuel, and cost management (Serrano-Hernandez et al., 2022).

Use of big data related to transportation (A5.2): Thanks to the use of big data, traffic flows can be improved, and delivery times can be reduced (Serrano-Hernandez et al., 2021). It can contribute to the reduction of time and costs by providing speed gain by organizing the routes of transport vehicles.

Remote controllability of vehicle (A5.3): It is thought that the remote controllability of transport vehicles contributes to costs as they reduce fuel consumption (Serrano-Hernandez et al., 2021). Remote-controllable vehicles have improved delivery management.

Methodology

In this study, fuzzy AHP was used as the research method. The AHP is a method used to contribute to the reduction of uncertainty by assigning numerical values to subjective evaluations. Therefore, it is considered appropriate to use this method in this study. Fuzzy AHP enables the transformation of criteria that are difficult to measure but important for the urban transport logistics of smart cities into numerical values. Fuzzy AHP contributes to the decision-making process by reducing the uncertainty in the evaluations of experts thanks to its fuzzy logic approach. Thanks to this method, the quantitative and qualitative data are used together. A survey of the literature was used to define the primary and secondary criteria. The main requirements for applying the Fuzzy AHP approach to evaluate the effectiveness of urban freight logistics in smart cities were determined to be the relevant disciplines. An analytical hierarchical structure was created as a result of the discovery of 24 sub-criteria. Ethics approval was obtained from the Social Sciences and Humanities Research and Publication Ethics Committee at Istanbul Kent University (Date: 10.05.2024, Decision no: 7). To collect expert opinions, a questionnaire will be completed by individuals working in five related disciplines. Five experts were consulted for their assessments. The professions of the experts consisted of logistics experts in the private sector and academicians working on the subject (Table 2).

Table 2

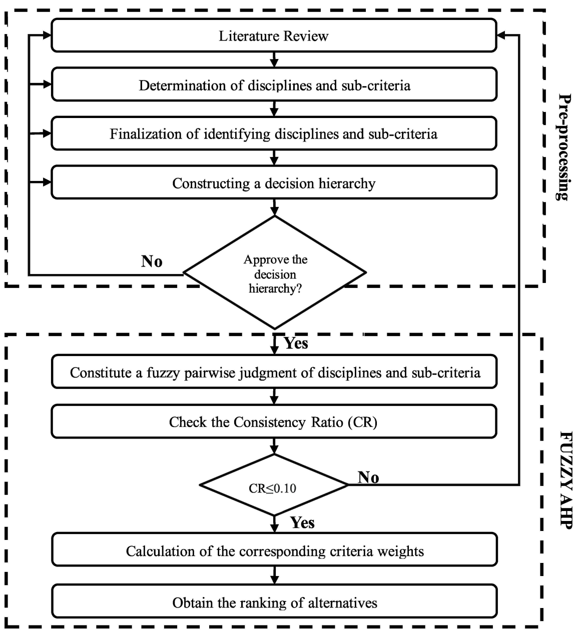
Occupational distribution of experts

Experts	Occupations
Expert 1	Logistics Operations Manager
Expert 2	Academician
Expert 3	Transportation Coordinator
Expert 4	Distribution Officer
Expert 5	Academician

The experts were contacted via email and invited to complete a questionnaire comparing and scoring the criteria and sub-criteria. The questionnaire included a sample question that asked about the significance of various environmental science criteria in measuring the performance of urban freight logistics in smart cities. In the first instance, the experts compared the respective disciplines and determined their levels of importance. Subsequently, the sub-criteria for urban freight logistics in smart cities were compared against their respective disciplines' criteria, and their importance levels were determined. The importance levels thus determined were then used to calculate the geometric mean. Subsequently, the weight of each sub-criterion was multiplied by the weight of the discipline to which it belonged, thereby defining the final weight of each sub-criterion. This procedure was repeated for each sub-criterion. The ultimate rankings were established by prioritizing the different criteria to determine which one holds greater significance in assessing the effectiveness of urban transportation logistics in smart cities. It is imperative that the matrices created adhere to a consistency ratio below 10%; should this threshold be exceeded, the inconsistent criteria must be identified and eliminated. Figure 1 shows a schematic of the research framework.

Figure 1

Research design



When employing the AHP approach, a positively valued pairwise comparison matrix A of size n × n is utilized (Ramík and Korviny, 2010):

$$\mathrm{A} = \begin{bmatrix} 1 & \alpha_{12} & \cdots & \alpha_{1n} \\ \alpha_{21} & 1 & \cdots & \alpha_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \alpha_{n1} & \alpha_{n2} & \cdots & 1 \end{bmatrix} \tag{1}$$

Matrix A is reciprocal if $\alpha_{\mathrm{ij}} = \frac{1}{2_{\mathrm{ij}}}$ for each $1 \leq i, j \leq n$.

Matrix A is consistent if $\alpha_{\mathrm{ij}}.\alpha_{\mathrm{jk}} = a_{\mathrm{ik}}$ for each $1 \leq i, j, k \leq n$.

If the condition in case 2 does not hold, A can be said to be inconsistent.

In the traditional AHP approach, the inconsistency of matrix A is assessed using the consistency index. This is determined by calculating the Consistency Index (CI) using the method outlined in Holecek and Talašová (2016):

$$\mathrm{CI} = \frac{\lambda_{\max} - n}{n - 1} \tag{2}$$

The decision's consistency is verified through the consistency ratio. The term "Random Index" (RI) denotes the random consistency index, the values of which are provided in Table 3.

Table 3

Random consistency index

Size of the matrix	1	2	3	4	5	6	7	8	9	10
Random consistency index (RI)	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

Source: Saaty, 1980

The evaluation of urban freight logistics performance in smart cities via the Fuzzy Analytic Hierarchy Process Method is a multifaceted undertaking.

The development of the criteria is a fundamental stage in the process. The initial stage entails the identification of criteria associated with enhancing the efficacy of urban freight logistics in smart urban environments. This process is informed by the findings derived from a comprehensive review of the extant literature. The proposed scheme necessitates the inclusion of primary criteria from the fields of environmental science, economics, transport engineering, computer science and urban planning.

Weighting of Criteria: after the establishment of the criteria, the subsequent action was to allocate weights to each criterion according to the degree of its importance. The weight assignment was conducted utilizing the Fuzzy AHP approach. The significance of each criterion was evaluated on a scale of one to 9. The concept of fuzzy pair-wise comparison entails the comparison of two or more items based on a set of criteria, where the degree of similarity or difference between the items is represented by fuzzy numbers. Abbreviations of technical terms shall be explained with their first use. The third stage involves a pairwise evaluation of the sub-criteria for the performance of urban freight logistics in smart cities using the criteria identified in the first stage. The fuzzy AHP methodology employs a fuzzy logic-based approach to manage and address data uncertainty effectively. Pairwise comparisons were made using language variants such as "equally important," "moderately important," and "very strongly important."

For this study, the interval scale is used, whereas in classical AHP, the scale follows 1/9, 1/8,...,1/2,1, 2, ..., 8,9 (Table 4). This scale was used because it provides a more balanced comparison compared to other classical fuzzy scales and is more effective in group decisions and analyses involving risk (Shah et., 2019).

Table 4

Linguistic scoring and triangular fuzzy numbers

Linguistic Judgment	Fuzzy Value	Triangular Fuzzy Scale	Complementary Scale
Equally Important	1	1, 1, 1	1, 1, 1
Moderately Important	3	2, 3, 4	1/4, 1/3, 1/2
Strongly Important	5	4, 5, 6	1/6, 1/5, 1/4
Very Strongly Important	7	6, 7, 8	1/8, 1/7, 1/6
Extremely Important	9	8, 9, 9	1/9, 1/9, 1/8

Source: Shah et., 2019

Priority Weight Determination: Priority weight determination involves calculating the sub-criteria weights for the urban freight logistics performance in each smart city. This process determines the relative importance of the performance sub-criteria.

The weighted average $w_k = (w_k^L, w_k^M, w_k^U), k = 1, 2, ..., n$, is calculated as per the procedure outlined by Ramík and Korviny (2010):

$$\mathrm{C}_{\min} = \min_{\mathrm{i}=1,\ldots,n} \left\{ \frac{\left(\prod_{j=1}^{n} a_{ij}^{M}\right)^{1/n}}{\left(\prod_{j=1}^{n} a_{ij}^{L}\right)^{1/n}} \right\} \text{ when } w_k^L = \mathrm{C}_{\min} \cdot \frac{\left(\prod_{j=1}^{n} a_{kj}^{L}\right)^{1/n}}{\left(\prod_{j=1}^{n} a_{kj}^{M}\right)^{1/n}} \tag{3}$$

$$w_k^M = \frac{\left(\prod_{j=1}^{n} a_{kj}^{M}\right)^{1/n}}{\left(\prod_{j=1}^{n} a_{ij}^{M}\right)^{1/n}}, \tag{4}$$

$$\mathrm{C}_{\max} = \max_{\mathrm{i}=1,\ldots,n} \left\{ \frac{\left(\prod_{j=1}^{n} a_{ij}^{M}\right)^{1/n}}{\left(\prod_{j=1}^{n} a_{ij}^{U}\right)^{1/n}} \right\} \text{ when } w_k^L = \mathrm{C}_{\min} \cdot \frac{\left(\prod_{j=1}^{n} a_{kj}^{U}\right)^{1/n}}{\left(\prod_{j=1}^{n} a_{kj}^{M}\right)^{1/n}} \tag{5}$$

Findings

Determination of the Criteria

Following a thorough review of the extant literature, 25 relevant studies were identified in the Scopus index and WOS. The earliest study dates back to 2014. A subsequent analysis of the distribution of studies over time has revealed an increasing interest in urban freight logistics in smart cities. Of the 25 studies, 14 are research articles, 6 are review articles and 5 are papers. The literature review has identified five disciplines of urban freight logistics in smart cities that may hold relatively greater significance compared to other disciplines, by virtue of their association with urban freight logistics in smart cities. The identification of these disciplines was facilitated through the utilization of keywords, titles and journals of the studies. The analysis revealed that five studies were affiliated with environmental science, ten with transport engineering, five with urban planning, four with computer science, and three with economics. It is notable that several studies were related to more than one discipline (Table 5).

Table 5
Urban freight logistics in smart city-related studies

Author	Year	Type	Discipline	Results
Büyüközkan and Ilıcak	2022	Review Article	-	Analyze sub-topics and new technologies in the field of smart urban logistics.
Büyüközkan and Mukul	2019	Research Article	-	Safety and emergency systems have emerged as the most important criteria in the evaluation of smart urban logistics solutions.
Cerrone and Sciomachen	2022	Research Article	Environmental Science	Test scenarios using data from two B2C enterprises' distribution networks showed that the proposed methodologies can be used to create sustainable urban distribution plans.
Dohn et al.,	2022	Research Article	Transportation Engineering	A low level of cooperation between local authorities and key city logistics stakeholders.
Dudek and Kujawski	2022	Research Article	Transportation Engineering	Big data management with multiple transportation system sources as a vital role in smart city development requires extra methods and algorithms to rectify multi-camera image recognition system forecasts.
Gatta et al.,	2017	Research Article	Urban Planning	Expanding knowledge of new context-specific Urban Freight Transport policies. Incorporating UFT policies into comprehensive urban planning through collaborative participation and governance approaches.
Guimarães et al.,	2021	Research Article	Transportation Engineering	The applied model might support the design of smart cities.
He and Haasis	2020	Review Article	-	The foundation for theoretical exploration regarding long-term strategies for sustainable urban freight transport in smart cities is constructed upon two prospective perspectives: trends in urban development and the incorporation of innovations in urban distribution.
Karakikes , Nathanail	2017	Research Article	Information Technology	Simulation is an effective tool for evaluating the impacts of logistics solutions before their real-world implementation, thereby aiding the decision-making process.
Kim et al.,	2020	Research Article	Information Technology Transportation Engineering	The proposed model appears to be feasible, and the developed heuristic yields highly effective operational plans regarding both the optimality gap and the computation time.

Author	Year	Type	Discipline	Results
Korczak and Kijewskab	2018	Review Article	-	Sophisticated technologies in smart cities and smart logistics do not benefit stakeholders; instead, solutions that make sense of the data gathered must be developed.
Lu	2014	Conference Paper	Urban Planning	Discusses how logistics clusters must work together to improve urban logistics in Europe systemically for sustainable urban environments.
Marciania and Cossu	2014	Conference Paper	Information Technology Transportation Engineering	The goal of the URBeLOG project is to create and validate a system for the transportation of virtuous goods that will reduce last-mile service costs, streamline operations, and make them more eco-friendly.
Mejía et al.,	2019	Conference Paper	Information Technology Transportation Engineering	The suggested approach demonstrated significant advantages over the current state of affairs when evaluated using real-time traffic and airport cargo area status data.
Melo et al.,	2017	Research Article	Urban Planning Transportation Engineering	In addition to reducing travel times, rerouting can improve traffic performance at the route level of analysis and the effectiveness of the city network's roads.
Nathanail et al.,	2016	Research Article	Environmental Science Urban Planning	An integrated assessment approach for city logistics that considers the life cycle of smart solutions as well as the complexity of combining interurban and urban freight transport.
Navarro et al.,	2016	Conference Paper	Environmental Science Economics	demonstrates the outcomes of a live test of smart city urban logistics solutions in Valencia and Barcelona, which involved integrating the usage of transshipment facilities with electric tricycles for small shipment and parcel last-mile delivery.
Pan et al.,	2021	Review Article	-	A new smart city conceptual framework with the pertinent main viewpoints for sustainable urban freight logistics.
Ranieri et al.,	2018	Review Article	Economics	creative vehicles, proximity to stations or points, cooperative and collaborative urban logistics, transportation management and routing optimization, and innovations in public policies and infrastructures are the five primary areas.

Author	Year	Type	Discipline	Results
Reyes Rubiano et al.,	2021	Review Article	Environmental Science Transportation Engineering	The operation research models seek to achieve a higher threshold in the sustainable transport standards in smart cities.
Russo and Comi	2021	Research Article	Information Technology	Operators and collectives play a significant role in improving the sustainability and livability of cities.
Shee et al.,	2021	Research Article	Economics Transportation Engineering Information Technology	Smart logistics benefits greatly from the use of information and communications technologies (ICTs) and IT competency (ITC).
Serrano-Hernandez et al.,	2021	Research Article	Transportation Engineering	The last mile in the selection of freight transportation modes in urban areas. - The social dimension is valued much more than the economic or environmental dimensions. - Drones are seen as the best alternative for city center deliveries. Avoid entering the city center is preferred for drones and vans.
Škultéty et al.,	2021	Research Article	Urban Planning Environmental Science	The analysis demonstrates how supply chain management and city logistics may be planned using the clusters.
Zysińska	2020	Conference Paper	Urban Planning	Describes the difficulties and impediments in developing and implementing contemporary urban logistical solutions.

Weighting of the Criteria

The criteria were evaluated, and the experts determined the following weights through comparison.

Table 6

fuzzy matrix of the main criteria

	A1	A2	A3	A4	A5
A1	1 1 1	0.871 1.107 1.431	2.352 3.005 3.776	0.803 1.000 1.246	2.000 2.627 3.366
A2	0.699 0.903 1.149	1 1 1	2.074 2.853 3.565	1.320 1.552 1.741	1.741 2.667 3.288
A3	0.265 0.333 0.425	0.280 0.351 0.461	1 1 1	0.322 0.394 0.500	0.922 1.246 1.644
A4	0.803 1.000 1.246	0.574 0.644 0.758	2.000 2.537 3.104	1 1 1	2.297 2.954 3.565
A5	0.341 0.422 0.542	0.349 0.467 0.660	0.608 0.803 1.084	0.280 0.339 0.435	1 1 1
Consistency Test: 0.009					

As demonstrated in Table 6, transport engineering emerged as the pivotal domain for assessing the effectiveness of smart cities' urban freight logistics, with a score of 0.286. The refinement of urban freight logistics is an integral component of a well-functioning smart city, underscoring the necessity for involving transport engineering. In addition, environmental science was identified as the second most critical field, with a rating of 0.275 (Figure 2). A fundamental objective of smart cities is to promote healthy and sustainable activities. Consequently, the significance of environmental science in relation to the efficacy of urban freight logistics in smart cities cannot be overstated.

Figure 2

Ranking of the main criteria

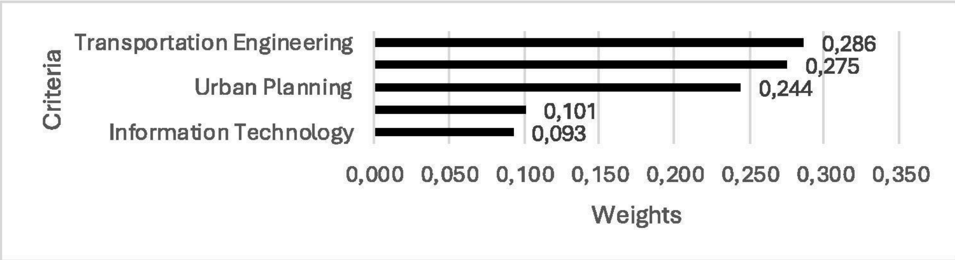


Figure 3 displays the transport engineering criterion matrix, which ranks the criteria as A2.1<A2.2<A2.3<A2.5<A2.4.

Table 7

Fuzzy matrix of the transportation engineering criteria

	A2.1	A2.2	A2.3	A2.4	A2.5
A2.1	1 1 1	0.660 0.889 1.246	0.488 0.654 0.871	0.281 0.338 0.435	0.281 0.338 0.435
A2.2	0.803 1.125 1.516	1 1 1	0.561 0.654 0.758	0.322 0.422 0.574	0.322 0.415 0.574
A2.3	1.149 1.528 2.048	1.000 1.108 1.246	1 1 1	0.281 0.338 0.435	0.740 0.803 0.871
A2.4	2.639 3.680 4.704	1.516 1.904 2.352	1.516 2.141 2.862	1 1 1	1.000 1.165 1.320
A2.5	2.297 2.954 3.565	1.516 1.933 2.352	0.803 0.903 1.024	0.758 0.859 1.000	1 1 1
Consistency Test: 0.013					

As illustrated in Table 7, the most significant transport engineering criterion when assessing the performance of urban freight logistics in smart cities is the optimization of route planning (0.341). The enhancement of route planning has been shown to engender improved load distribution, reduced urban congestion, and facilitated capacity sharing (Jones et al., 2022). Consequently, the optimization of route planning may hold greater importance for the performance of urban freight logistics in smart cities than other transport engineering criteria. Capacity sharing was identified as the second most significant factor (0.270). The utilization of capacity sharing permits optimization based on capability and capability assessment. This underscores the pivotal role of capacity sharing in enhancing the efficiency of urban freight logistics within smart cities.

Figure 3

Ranking of the transportation engineering criteria

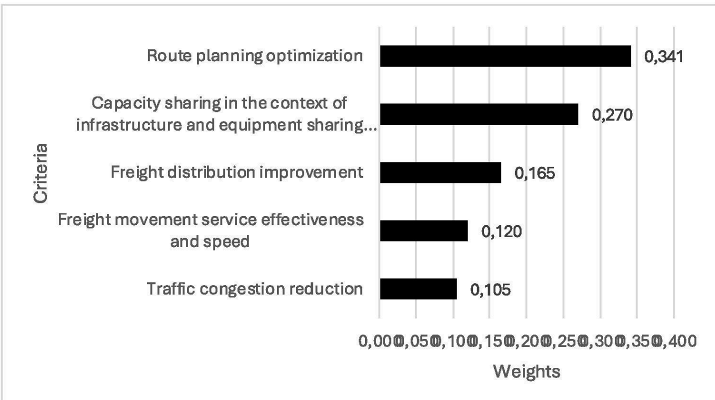


Figure 4 displays the matrix of the environmental science standards. As a result, the standards are ordered as A1.6<A1.3<A1.3<A1.1<A1.5<A1.4<A1.2.

Table 8

Fuzzy matrix of the environmental science criteria

	A1.1	A1.2	A1.3	A1.4	A1.5	A1.6
A1.1	1 1 1	0.201 0.254 0.349	1.320 1.552 1.741	0.500 0.644 0.871	0.608 0.803 1.084	0.841 1.136 1.565
A1.2	2.862 3.936 4.983	1 1 1	2.491 3.160 3.776	2.000 2.667 3.288	3.031 3.624 4.193	4.000 5.097 6.000
A1.3	0.574 0.644 0.758	0.185 0.229 0.304	1 1 1	0.280 0.338 0.435	0.530 0.582 0.660	1.000 1.316 1.682
A1.4	1.320 1.933 2.639	0.304 0.375 0.500	2.000 2.667 3.288	1 1 1	0.660 0.803 1.000	1.278 1.732 2.213
A1.5	0.871 1.108 1.380	0.238 0.276 0.330	1.516 1.933 2.297	1.000 1.246 1.516	1 1 1	1.189 1.732 2.378
A1.6	0.639 0.880 1.189	0.167 0.196 0.250	0.595 0.760 1.000	0.452 0.577 0.783	0.420 0.577 0.841	1 1 1
Consistency Test: 0.019						

As demonstrated in Table 8, the primary environmental science factor to evaluate the performance of urban freight logistics in smart cities is sustainability (0.410). The performance of urban freight logistics in sustainable smart cities is robust as it is aligned with the objectives of the smart city. The second essential environmental science criterion for measuring urban freight logistics performance in smart cities is environmental pollution (0.163). Smart cities, as urban hubs, should be structured in a manner that promotes healthier lifestyles for their inhabitants. Consequently, environmental pollution emerges as the second most crucial ecological consideration among the broader spectrum of environmental science factors.

Figure 4

Ranking of the environmental science criteria

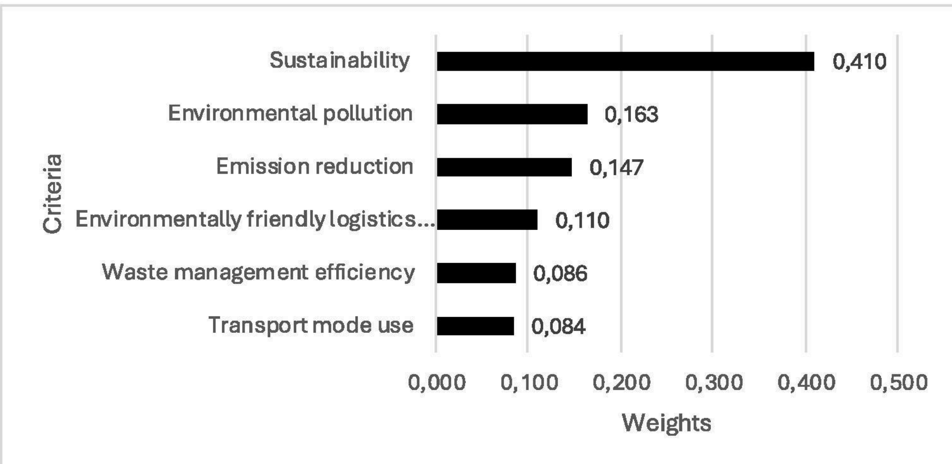


Figure 5 displays the matrix of criteria for urban planning, with rankings indicating that A4.1<A4.5<A4.5<A4.2<A4.3<A4.6<A4.4.

Table 9

Fuzzy matrix of the urban planning criteria

	A4.1	A4.2	A4.3	A4.4	A4.5	A4.6
A4.1	1 1 1	0.500 0.644 0.871	0.461 0.582 0.758	0.213 0.272 0.379	0.608 0.725 0.871	0.185 0.229 0.304
A4.2	1.149 1.552 2.000	1 1 1	0.411 0.517 0.699	0.231 0.301 0.435	1.398 1.933 2.491	0.370 0.422 0.500
A4.3	1.320 1.718 2.169	0.871 1.125 1.398	1 1 1	0.530 0.612 0.699	1.059 1.379 1.783	0.530 0.612 0.699
A4.4	2.639 3.680 4.704	1.398 1.933 2.491	2.169 2.537 2.862	1 1 1	2.639 3.680 4.704	0.660 0.803 1.000
A4.5	1.217 1.552 1.888	0.488 0.582 0.715	0.322 0.422 0.574	0.213 0.272 0.379	1 1 1	0.370 0.422 0.500
A4.6	3.288 4.360 5.404	2.000 2.371 2.702	1.431 1.635 1.888	1.000 1.246 1.516	2.000 2.371 2.702	1 1 1
Consistency Test: 0.018						

As demonstrated in Table 9, the pivotal urban planning criterion for evaluating smart city transport logistics performance is identified as the necessity for a flexible and sustainable urban transport system (0.286). Table 8 underscores the pivotal urban planning criterion for evaluating smart city transport logistics performance as the necessity for a flexible and sustainable urban transport system (0.286). The establishment of such a system facilitates the delineation of objectives and the identification of tasks that are essential for the enhancement of urban freight logistics performance in smart cities. The construction and enhancement of the logistics facilities' infrastructure emerged as the second most critical urban planning criterion (0.279). The minimization of loading and unloading periods in well-structured logistics facilities and distribution centers is instrumental in curtailing travel expenditures.

Figure 5

Ranking of the urban planning criteria

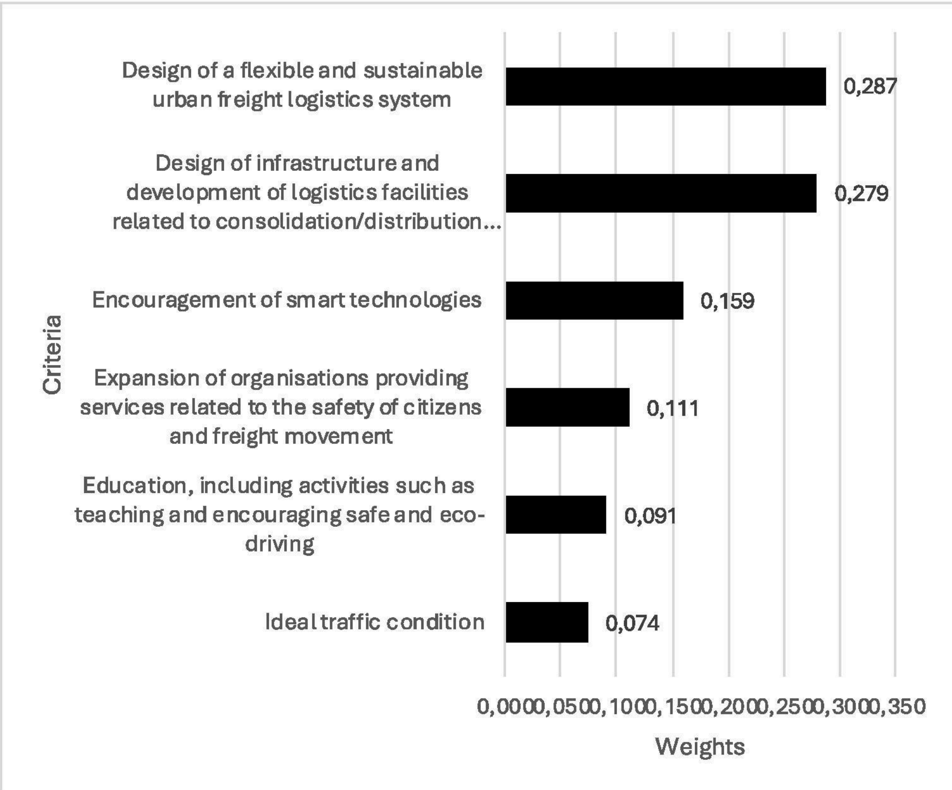


Figure 6 displays the economic criteria matrix, which assigns rankings with A3.1 <A3.3 <A3.2 <A3.4 < A3.5.

Table 10

Fuzzy matrix of economics criteria

	A3.1	A3.2	A3.3	A3.4	A3.5
A3.1	1 1 1	0.185 0.229 0.304	0.213 0.272 0.379	0.265 0.316 0.401	0.171 0.207 0.265
A3.2	3.288 4.360 5.404	1 1 1	1.149 1.552 2.000	0.231 0.301 0.435	0.250 0.333 0.500
A3.3	2.639 3.680 4.704	0.574 0.714 0.944	1 1 1	0.370 0.467 0.623	0.280 0.339 0.435
A3.4	2.862 3.936 4.983	2.000 2.667 3.288	2.297 2.954 3.565	1 1 1	0.871 1.000 1.149
A3.5	2.862 3.500 4.095	1.741 2.408 3.031	2.297 2.954 3.565	0.871 1.000 1.149	1 1 1
Consistency Test: 0.057					

As demonstrated in Table 10, the predominant economic criterion for evaluating the urban freight logistics performance in smart cities is the enhancement of resource and energy efficiency in product transportation (0.350). The implementation of this criterion is expected to reduce expenses for transport companies. Given that product transportation constitutes their primary activity, a substantial decrease in expenses will occur. Consequently, it can be regarded as the predominant economic measure by experts. The second most significant economic criterion (0.307) is the transportation and logistics expenses, which impact the company's delivery speed and accuracy.

Figure 6

Ranking of economic criteria

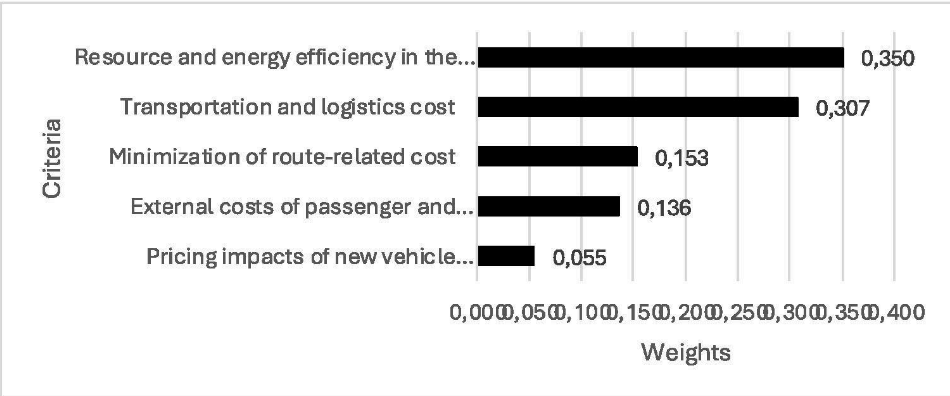


Figure 7 displays the computer criterion matrix and ranks the criteria as A5.1<A5.2<A5.3.

Table 11

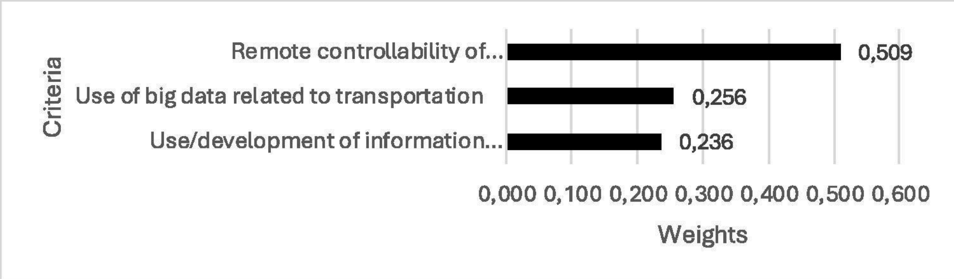
Fuzzy Matrix of Information Technology

	A5.1	A5.2	A5.3		
A5.1	1 1 1	0.803 1.125 1.516	0.297 0.381 0.500	A5.2	0.66 0.889 1.246
1 1 1	0.530 0.612 0.699	A5.3	2.00 2.627 3.366	1.888 2.036 2.169	1 1 1
Consistency Test: 0.038					

As illustrated in Table 11, the predominant computer criterion for evaluating the performance of urban freight logistics in smart cities is the capacity for remote control of transportation (0.509). The utilization of such vehicles has been demonstrated to reduce fuel consumption, thereby generating financial savings. Furthermore, the utilization of remote-controllable transport vehicles contributes to the mitigation of pollution and the promotion of sustainability.

Figure 7

Ranking of information technology criteria



Calculation of the Final Weights

Table 12 displays the ultimate weights attained by multiplying the ratio weight of the sub-criteria by the main weight of the main criteria.

Table 12

Final weights of the sub-criteria

Main Criteria	Weights of the Main Criteria	Sub criteria	Ratio Weight	Consistency Test	Final Weight
(A1) Environmental Science	0.275	A1.1	0.110	0.019	0.030
		A1.2	0.410		0.113
		A1.3	0.086		0.024
		A1.4	0.163		0.045
		A1.5	0.147		0.04
		A1.6	0.084		0.023
(A2) Transportation Engineering	0.286	A2.1	0.105	0.013	0.030
		A2.2	0.120		0.034
		A2.3	0.165		0.047
		A2.4	0.341		0.098
		A2.5	0.270		0.077
(A3) Economics	0.101	A3.1	0.055	0.057	0.006
		A3.2	0.153		0.015
		A3.3	0.136		0.014
		A3.4	0.307		0.031
		A3.5	0.350		0.035
(A4) Urban Planning	0.244	A4.1	0.074	0.018	0.018
		A4.2	0.111		0.027
		A4.3	0.159		0.039
		A4.4	0.287		0.07
		A4.5	0.091		0.022
		A4.6	0.279		0.068
(A5) Information Technology	0.093	A5.1	0.236	0.038	0.022
		A5.2	0.256		0.024
		A5.3	0.509		0.047

As illustrated in Table 13, the hierarchy of importance for performance criteria regarding urban freight logistics in smart cities is as follows: sustainability (11.3%), optimizing route planning (9.8%), and sharing capacity for infrastructure and equipment across various modes of transport (7.7%). Sustainability (11.3%) was the foremost sub-criterion among the performance criteria, followed by optimizing route planning (9.8%) and sharing capacity for infrastructure and equipment across various modes of transport (7.7%). The least significant factors include the impact of new vehicle technologies on road systems' prices (0.6%), passenger and freight transport's external costs (1.4%) and cost reduction measures for routes (1.5%). Generally speaking, cost-effectiveness and speed are the most crucial elements in urban freight logistics. While acknowledging the significance of these elements, this study also forecasts that prioritizing sustainability-oriented initiatives will have a favorable macro-level impact on society and overall performance.

Table 13

Importance of the sub criteria ranking

Subcriteria	Definitive weight percentages
Sustainability	11.3
Route planning optimization	9.8
Capacity sharing in the context of infrastructure and equipment sharing between different transport modes	7.7
Design of a flexible and sustainable urban freight logistics system	7
Design of infrastructure and development of logistics facilities related to consolidation/distribution centers and logistics	6.8
Freight distribution improvement	4.7
Remote controllability of vehicle	4.7
Environmental pollution	4.5
Emission reduction	4
Encouragement of smart technologies	3.9
Resource and energy efficiency in the transportation of good	3.5
Freight movement service effectiveness and speed	3.4
Transportation and logistics costs	3.1
Traffic congestion reduction	3
Environmentally friendly logistics activities	3
Deployment of organizations ensuring the safety of citizens and their connection to different urban areas	2.7
Use of big data related to transportation	2.4
Waste management efficiency	2.4
Transport mode use	2.3
Use/development of information technologies	2.2
Education, including activities such as teaching and encouraging safe and eco-driving	2.2
Ideal traffic condition	1.8
Minimization of the route-related cost	1.5
External costs of passenger and freight transport	1.4
Pricing effects of new vehicle technologies on the road system	0.6

Conclusion

The objective of smart cities is to enhance the quality of life of their inhabitants. Urban freight logistics in smart cities is of pivotal importance in fostering sustainable, efficient, and habitable urban environments. It encompasses the utilization of advanced technologies in the transportation of goods and services to contribute to the overall welfare and quality of the city. Given its ties to environmental science, economics, transportation engineering, computer science, and urban planning, an examination of the body of existing literature demonstrates the multidisciplinary nature of this topic. According to this study, the most crucial field for urban freight logistics performance in smart cities is transport engineering. The discipline of transport engineering refers to the design and implementation of vehicles and routes for the optimization of routes in urban freight logistics and the effective and efficient transport of loads. Therefore, it seems reasonable that transport engineering is the most important discipline in urban freight logistics in smart cities. It has been determined that the most important sub-criteria in urban freight logistics in smart cities is sustainability. Sustainability is one of the most important goals in the creation and development of smart cities. Therefore, it seems reasonable that the most important sub-criteria in urban freight logistics in smart cities is sustainability. According to this result, it is recommended that strategy makers for urban freight logistics in smart cities should develop urban freight logistics strategies with a sustainable focus. Such a strategy may include tactics and practices such as encouraging the use of cycling, walking and public transport, the use of delivery drones, route optimization algorithms and autonomous vehicles, and the creation of programs to encourage such vehicles and technologies. In general, the most important factors in urban freight logistics are speed and cost effectiveness. This study acknowledges the importance of these factors and predicts that giving importance to sustainability-oriented activities will positively affect the overall performance and society in the macro dimension.

The limitation of this study is that there are only five disciplines that are important for the performance of urban freight logistics in smart cities. Therefore, increasing the number of disciplines and sub-criteria will provide a more comprehensive assessment of the performance of urban freight logistics in smart cities. Another suggestion that can be given to researchers is to adapt this study to smart cities in their own countries. In this way, it will be possible to determine what kind of differences regional and urban differences may create from the urban freight logistics performance in smart cities. Another suggestion is to use a multi-criteria decision-making method other than the fuzzy AHP for urban freight logistics performance in smart cities. In this way, it can be determined what kind of changes will be made for the urban freight logistics performance in smart cities.

Ethics Committee Approval:	Ethics approval was obtained from the Social Sciences and Humanities Research and Publication Ethics Committee at İstanbul Kent University (Date: 10.05.2024, Decision no: 7).
Informed Consent	Informed consent was obtained from the participants.
Peer Review	Externally peer-reviewed.
Author Contributions	Conception/Design of Study- F.A.E., M.S.; Data Acquisition- M.N.U., B.D.; Data Analysis/Interpretation- F.A.E., M.S., M.N.U., B.D.; Drafting Manuscript- B.D., M.S.; Critical Revision of Manuscript- M.N.U., B.D.; Final Approval and Accountability- F.A.E., M.S., M.N.U., B.D.
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